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AIR POLLUTION SURVEY. REPORT 2. METEOROLOGY AND AIR POLLUTION IN THE DELAWARE VALLEY

John R. Mather

Regional Conference of Elected Officials
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LABORATORY OF CLIMATOLOGY

METEOROLOGY AND AIR POLLUTION IN THE DELAWARE VALLEY

FINAL REPORT

by

John R. Mather

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GENERAL PREFACE

The atmosphere is, by all odds, man's most vital natural resource. Until quite recently, we lived comfortably with the ambivalent views that (1) the atmosphere can be used freely for the disposal of the airborne waste products of an industrialized society, and (2) that people are, at all times, entitled to air in a form which will enable them to live cleanly, comfortably, and in good health.

With the recognition that we now dump more than 133 million tons of aerial garbage into the U. S. atmosphere each year, and recent grim reminders of possible mass death afforded us by stagnant, heavily polluted atmosphere over our metropolitan areas, that comfort no longer exists. As a society, it seems clear that we are irrevocably committed to the development of new public policy, new organizational and institutional forms, and new technology which will insure a safe, healthy atmosphere.

As unique evidence of that commitment, the Regional Conference of Elected Officials, Inc., (RCEO) has sponsored this study of the air pollution problem in the vast 11-county, tri-state region centered on Philadelphia. Part of the unique commitment to action is reflected in the financing arrangement for the study which involved a grant from the United States Public Health Service and the individual contributions of local units of government throughout the region. Further, this study effort provides new evidence that autonomous local units of government can join together in a cooperative venture to solve a common problem.

The Region, for purposes of this study, encompasses the three metropolitan areas of Philadelphia-Camden, Trenton, and Wilmington, located in Pennsylvania, New Jersey and Delaware respectively. The area extends generally along the Delaware River from Mercer County, New Jersey, in the north to New Castle County, Delaware, in the south. This area, about 4,545 square miles in extent and with a present population of over 5 million, forms an approximate rectangle 80 by 57 miles in size and oriented with the major axis NE-SW.

Exceeded only by the area centering on New York City, this Philadelphia tri-state region has the most complex governmental structure of any urban area in the United States, consisting of 11 counties and 377 municipalities in parts of three states.

The pattern of urban development and industrial concentrations makes it reasonable to consider the Region a discrete area for investigation of air pollution control problems. The urbanized portion of the Region is, in the main, concentrated along both sides of the Delaware River and rarely extends more than a dozen miles inland. A high percentage of the Region's 9,000 highly diversified manufacturing establishments are located within this band along the River.

The end objective of the study is to define the requirements for the development of an air resource management and control system appropriate to the solution of the problem in the 11-county tri-state Region, and, specifically, to determine the governmental machinery and arrangements through which such a system can operate effectively. The design of a viable management and control system for air pollution must be based on: (1) knowledge of the technical characteristics and dimensions of the problem in terms of the real and potential impact; (2) careful exploration and definition of major approaches in developing the technical methods and procedures to resolve the problem; and (3) construction of the optimal governmental framework, legal base, and administrative procedures through which the functional resolution of the problem can be implemented.

In keeping with this basic approach, the study was organized into three areas: 1) Emissions Survey, 2) Meteorological Analysis, and 3) Governmental Aspects. A separate component technical Report, each with a separate summary, has been prepared under each of these titles. The Emissions Survey was performed by Environmental Engineering and Science, Drexel Institute of Technology; The Meteorological Analysis was performed by C. W. Thornthwaite Associates Laboratory of Climatology; and the Governmental Aspects were analyzed by the Fels Institute of Local and State Government, University of Pennsylvania. A Report containing a review of study findings and implementation of study proposals accepted by RCEO will be prepared by the RCEO staff under Executive Director Chester A. Kunz, Rear Admiral, U. S. Navy, Retired.

The study operated under the general direction of the RCEO Air Pollution Committee with the Hon. John E. Babiarz, Mayor of Wilmington, Chairman.

The study benefited from the interest and efforts of the Technical Advisory Committee which was formed to provide general guidance and counsel at specific intervals. Committee members, representing the Air Pollution control agencies of the three states and the City of Philadelphia, were: Victor Sussman and Frank Willard, Jr., for Pennsylvania; William Munroe and Martin Sanvito, for New Jersey; John C. Bryson and James T. Wilburn, for Delaware; Arthur Wallach and Larry Himmelstein, for Philadelphia.

It should be noted that the findings, conclusions, and recommendations of the technical reports are the sole responsibility of the respective contractors, and the acceptance of these findings and conclusions along with recommendations for implementation will be the responsibility of RCEO.

The study is indebted to the many public and private officials of governmental agencies, business organizations, and civic groups which have cooperated through their sustained interest and active assistance. The efforts of all these participants can best be rewarded by the adoption of a program to insure a safe, healthy atmosphere for all citizens of the Region.

Regional Conference of Elected Officials

June, 1968

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ABSTRACT

The present study of meteorology and air pollution in the 11-county lower Delaware Valley area has involved an investigation of a) the availability of data and the existing and needed observational network; b) the monthly and annual air flow over the basin area; c) the stability conditions (frequency and distribution of inversions and mean mixing depths) that would influence the rate of mixing of the air with elevation; d) the varying air quality over the basin and its relation to synoptic meteorologic conditions; e) the possibility of using meteorologic conditions to forecast limiting pollution episodes; and f) detailed interpretation of several specific high pollution events.

Many conclusions are presented although a one-year study does not provide sufficient time to study all aspects of the problem. The duration of limiting meteorological events appears to be more favorable for pollution episodes in late summer and fall although it is only in winter that meteorological conditions combine with the abundance of pollution material to produce the highest levels of pollution. The importance of nonmeteorologic as well as meteorologic factors in air pollution makes it extremely difficult to forecast air quality from a knowledge of meteorologic factors or the weather map alone. The importance of nonmeteorologic factors, which can be manipulated or controlled, as opposed to the meteorologic factors which can only be understood but not controlled, indicates the important role that planners and other physical and social scientists must play in air pollution abatement.

A study of air quality suggests that serious but not extreme pollution conditions exist in the highly industrialized Delaware Valley. The potential for very serious pollution certainly exists. It is probably only because of the area's relatively favorable meteorologic situation, with few stagnant highs and persistent inversions, and its favorable topographic situation, with little opportunity for air to become trapped in valleys or basins, that more serious pollution episodes do not develop.

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CHAPTER I. INTRODUCTION

Concern about air pollution is a commonplace in today's society. Mark Twain felt that we all used to talk about the weather. Today our conversation is more concerned with the deteriorating air quality, and more importantly, people seem to be trying to do something about it. Stern (1957) points out that more attention is now being focused on air pollution than at any previous time, but that the increasing study we have brought to the problem has only allowed us to keep pace with the increasing seriousness of the problem. No real progress is being made. The increasing industrialization of an ever growing population which has steadily become more urbanized results in more waste products being introduced into the atmosphere; in many areas, under certain meteorological situations, the atmosphere can no longer safely disperse this pollution load.

Air pollution is a problem for everyone. Practically all avenues of life contribute to the problem by introducing waste products into the air. Thus, the industrialist with the belching factory, the worker who drives to work, the housewife who drives to school or market or burns the trash or leaves, the vacationer who directs his motor boat to a favorite fishing spot, the shipper whose trucks roar across the highways, the farmer who plows a dry field or who sprays or dusts for insects all contribute to the problem. At the same time air pollution is an engineering problem, a social or cultural problem, an economic problem, a chemical problem and, of course, a meteorological problem. The present report, which considers air pollution and meteorology in the Delaware Valley, thus, is a study of only one limited aspect in one small geographic area of an almost world-wide problem affecting a multitude of scientific disciplines, ways of life, and individuals. When viewed this way one might become almost apologetic for the meagreness of one's contribution; but it must be recognized that with such a complex and all-encompassing problem, there will be no single, unique, all-pervading solution; rather, the problem will have to be broken into smaller segments, each of which can be studied and solved by a small group of individuals working together. Only as each of the parts of the problem is studied and understood will the sum of the parts or the total problem be reduced in seriousness.

One waste products have been discharged to the atmosphere, their subsequent movement, concentration, or dispersal, and their final removal from the atmosphere become in large measure a meteorological problem. Certain changes in the pollutants might be chemical or physical, or possible even biological, but still meteorological influences are primary as far as the history of the waste products is concerned. Even though waste products may be introduced into the air at an almost constant rate, the day-to-day changes in meteorological conditions will, at times, render them harmless by dispersal and dilution and, at other times, concentrate them to a choking, odorous, possibly lethal density. Meteorological conditions determine whether the materials released here will affect conditions here or in some other place miles away.

Two meteorological elements are of primary concern in air pollution problems. They are the wind (wind speed and direction and their change with height) and the temperature structure through the lowest air layers.

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> "The wind direction is important in determining where air pollutants came from and where they are going. Wind direction may also serve as an indicator of the diluting power of the atmosphere. For example, light southerly winds in winter would result in the air being cooled from below and would generally indicate poor mixing and high concentration of pollutants near the surface. North westerly winds in winter would often produce opposite results.
>
> "The wind speed also affords a clue to the mixing power of the atmosphere. There is an inverse relationship between wind speed and contamination at the ground that is, the higher the wind speed, the lower the ground level concentration. . . .
>
> "The variation of both wind speed and wind direction with height, or wind shear, is also an indication of the tendency of the air to spread out, or dilute, contaminants. The greater the change in speed with height and the greater the change in direction with height, the greater the spreading of contaminants and the lower the ground concentration at any point.
>
> "Finally, the distribution of temperature with height is perhaps the most critical weather element which influences the degree of concentration of pollutants near the ground where they can adversely affect the health and daily living of people residing in the area. When the temperature decreases rapidly with height, the air near the surface has a tendency to rise, and pollutants are carried to high levels and thinned out. When the temperature increases with height, on the other hand, air at lower levels is colder and heavier than that above, and mixing is strongly inhibited. This, in turn leads to high concentration of pollutants near the ground level." (Davis, 1960, pp. 4-5)

Any study of meteorological conditions as related to air quality must therefore be concerned with wind and temperature data, not only as they exist at the surface but also as they vary both horizontally and vertically with time. Temperature and wind observations at the surface are available from a fairly large number of stations in all parts of the country so that we have a fair knowledge of their horizontal variation and the influence of certain local topographic or environmental features. Vertical profiles of wind or temperature are quite limited in extent and we have little or no direct information on the wind shear with height or the temperature structure of the atmosphere over large areas of our country.

The 11-county Delaware Valley area of concern in the present study is relatively well endowed with surface weather observing stations. More than 20 stations can be found from which values of hourly or three-hourly wind speeds and directions at or near the earth's surface can be obtained. However observations of wind at some level above the surface are taken regularly at only two

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places (at 250 ft on a stack near Delaware City, Delaware, and at several levels to 890 ft on the WFIL-KYW tower in Philadelphia) and profiles of air temperature through any significant layer of air are taken at only one place (various levels to 890 ft on the WFIL-KYW tower). No current observations above 890 ft are known in the whole area in spite of the importance of this information in air pollution studies. Information on wind and temperature structure above 890 feet must come from observations taken either more than a decade ago by a radiosonde (balloon-borne meteorological sensor that reports temperature, humidity and pressure by radio as the balloon rises through the atmosphere) station in Springfield, Delaware County, or currently by radiosonde stations in Pittsburgh, Washington, or New York. Such distant observations are of only limited usefulness in any analysis in the 11-county Delaware Valley area.

General Topography of the Delaware Valley

The 11-county Delaware Valley area lies almost entirely in the gently rolling piedmont or nearly flat coastal plain area of the mid-Atlantic states. It is generally bordered on the west by outlying ridges of the folded Appalachian Mountains which run in a northeast-southwest direction from Morristown, New Jersey, to just east of Easton, Allentown, and Reading, Pennsylvania. Figure 1 is a portion of a physiographic diagram of Pennsylvania and New Jersey by A. K. Lobeck which shows in general the principal physical features in most of the study area.

The coastal plain which extends in a broad band eastward from a line joining New York, Trenton, Philadelphia, and Wilmington is broken only by a cuesta, or small ridge, running from Red Bank, to Freehold, to Pemberton, and Clementon, New Jersey. Elevations along this cuesta, which has a steep face directed inland and a very gradual slope toward the ocean are generally less than one hundred feet above the surroundings, and so it does not influence the general meteorological situation significantly.

West of Philadelphia and covering a rectangular area from Chester, to Germantown, to Trenton, and westward to Norristown and Phoenixville, the rolling piedmont borders the coastal plain. Here the topography is definitely hilly or rolling with elevations to several hundred feet and repeated alternations of valleys and hills. Northwest of this so-called Trenton prong of the piedmont lies a fairly broad and flat Triassic lowland including Pottstown, Doylestown, Lambertville, and Flemington. A number of small northeast-southwest ridges exist in this lowland but they are not sufficient to cause any modification of the general atmospheric circulation. Finally west of the lowland formation are found the foothills of the folded Appalachians with elevations of 500 to 1000 ft msl. These hills (Schooley Mt., Musconetcong Mts., Trap Mt.) essentially border the northwestern part of the area and may result in some local disturbances to air flow.

Within the area, stream valleys may afford some local relief features that will influence local concentration or dispersal of pollution but it is clear that the topography in the broad study region can play only a minor role in air pollution.

Davis has considered the topography of the immediate Philadelphia area and his conclusions are applicable to almost all of the 11-county study area.

> "Philadelphia is located on the Atlantic Coastal Plain, some 50 miles or more from the nearest mountains (Appalachian) and large bodies of water (Atlantic Ocean and Delaware Bay). The land and sea breeze effect is practically never felt at Philadelphia and the mountain-valley circulation is non-existent.
>
> "Within the city itself, there are very few marked extremes in topography. Elevations range from sea level at the southern and southwestern extremities of the city to 400 to 450 feet above sea level in the northwestern section (Chestnut Hill), about 10 miles away. The Wissahickon Creek and the Schuylkill River flow through the northwestern part of the city, however, and along these two streams there are some rather sharp rises in elevation, as much as 100 to 200 feet in a horizontal distance of 500 feet. Such extremes are quite limited and would not influence the meteorological patterns which affect the city as a whole. They could, of course, contribute to increased air pollution problems in a small local area within the city under certain circumstances.
>
> "In general, the topography of the city and the immediate surrounding area is such that it would make no significant contribution to increased air stagnation and stability over and above that produced by the meteorological pattern." (Davis, 1960, p. 15)

General Meteorology of Delaware Valley Area

The Delaware Valley area, located in mid-latitudes on the eastern side of the country is primarily influenced by the movement of migratory cyclones and anticyclones from the west. Thus, while most of the area is less than 200 miles from the Atlantic Ocean, it experiences much more of a continental climatic regime than a maritime one. As one would expect in a mid-latitude situation, the weather is quite variable with a regular sequence of good and bad days alternating in almost all seasons of the year.

Klein (1957) showed that about 40 percent of the cyclones that influence the weather in the United States pass northeastward toward the St. Lawrence Valley or the New England states over part of the 11-county area. Most of the remaining low pressure centers pass close enough to have some effect on the weather in the area.

Pressure systems move more slowly in summer than in winter. Thus, there is an increased opportunity for high pressure centers with their light winds and stable atmospheric conditions to stagnate over the area for periods of several days in late summer or fall. This can actually occur in any season

PHYSIOGRAPHIC DIAGRAM OF THE DELAWARE VALLEY AREA AND SURROUNDINGS

(Diagram is a portion of the physiographic diagram of Pennsylvania by A.K. Lobeck, 1951 © Hammond Incorporated No. 10306, reproduced with permission)

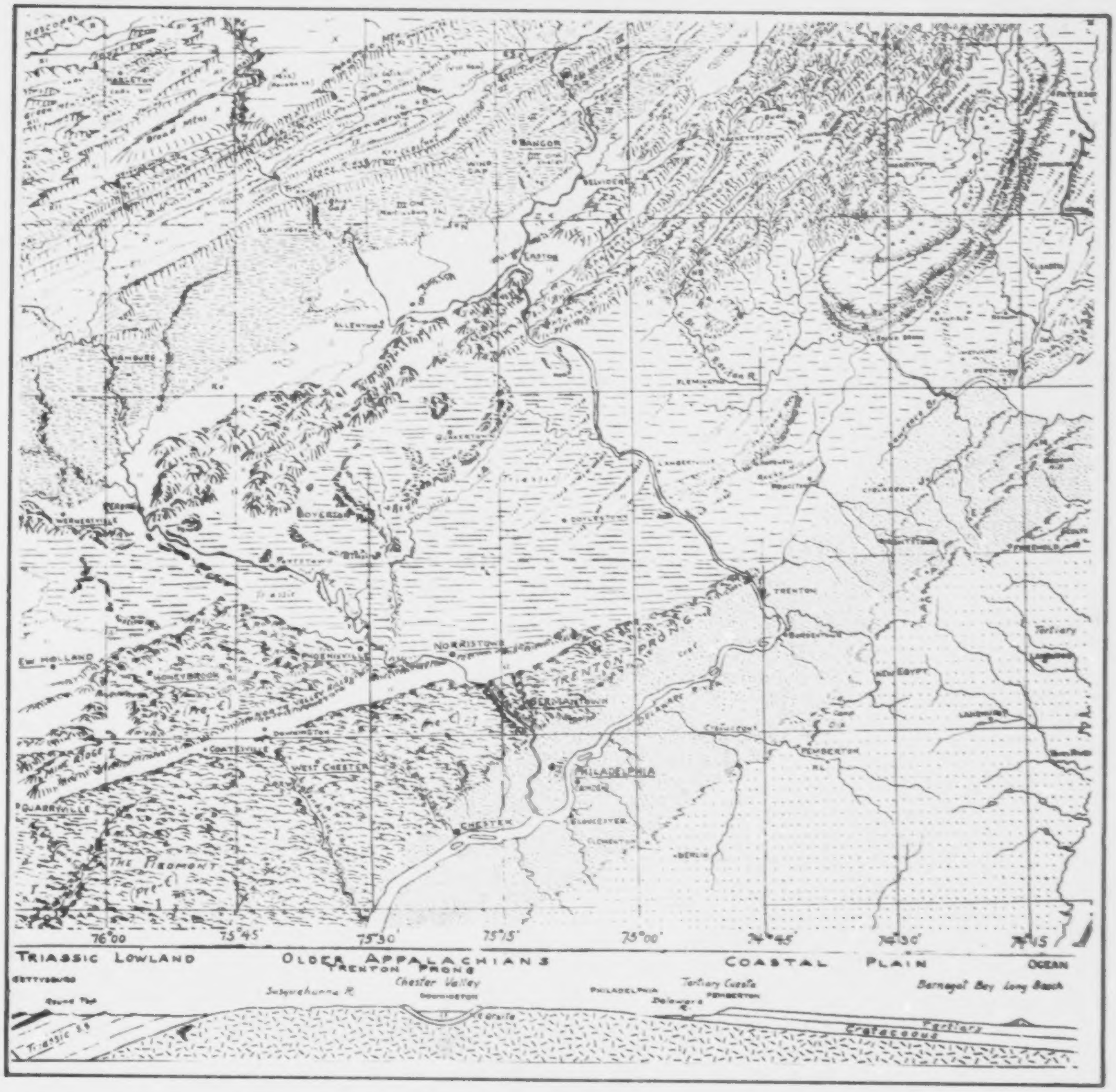

BANGOR
EASTON
ALLENTOWN
BOYERTOWN
NORRISTOWN
TRENTON
TRENTON PRONG
HONEYBROOK
COATESVILLE
WEST CHESTER
PHILADELPHIA
CHESTER
QUARRYVILLE
THE PIEDMONT
PEMBERTON
NEW EGYPT
Tertiary
76°00'
75°45'
75°30'
75°15'
75°00'
74°45'
74°30'
74°15'
TRIASSIC LOWLAND
OLDER APPALACHIANS
TRENTON PRONG
COASTAL PLAIN
OCEAN
Susquehanna R.
Chester Valley
PHILADELPHIA
Tertiary Cuesta
PEMBERTON
Delaware R.
Barnegat Bay
Long Beach
Tertiary
Cretaceous
Triassic

Figure 1

of the year but the decreased atmospheric circulation in summer and the possible location of the southern edge of westerlies aloft north of the basin area in summer increases the opportunities for stagnation at that time.

Because of the alternating cyclones and anticyclones in the mid-latitude region, persistent periods of stability or stagnant conditions do not occur frequently. Machta, Scott and Korshover (1958) showed that pressure systems associated with winds less than 7 mph for periods of 7 or more consecutive days occurred only once in 21 years in this area. Periods of such light winds for 4 or more days occurred much more frequently with the maximum month of occurrence being October. They found that such conditions existed once every three years in October alone.

Air masses that influence the Delaware Valley area are primarily maritime tropical (in summer) and continental polar (in spring, fall, and winter). From time to time short incursions of maritime polar air from the North Atlantic cover the area, often as part of the flow around low pressure areas moving northeastward up the Atlantic coast (three-day northeasters) but the great bulk of the air masses are either very warm, moist mT masses from the Gulf of Mexico or cold, dry cP air masses from Canada or midwestern United States.

The condition of the air mass as it approaches the Delaware Valley area is quite important in determining how it will influence air quality in the region. Maritime tropical air masses are warmer than their surroundings generally and so are cooled from below. They become more stable as they move north- and eastward across the area and, when associated with nighttime cooling, can result in a large number of temperature inversions at night. Daytime heating, which is appreciable in summer, often breaks up these inversions before they become too serious. Continental polar air is cold and dry. Thus, as it approaches the Delaware Valley it is being warmed and made more unstable from below by heating. Oftentimes associated with strong northwesterly winds, these air masses may result in periods of reduced pollution through turbulent mixing and unstable atmospheric conditions.

Stability and Instability in the Air

The normal rate of change of temperature with height is a decrease of about 3-4°F/1000 ft. The atmosphere receives its heat principally from the earth's surface by longwave radiation and by conduction-convection so that as one goes upward from the source of heat, temperature should decrease. This normal condition is called the temperature lapse rate.

Under certain conditions, with cooling of the earth's surface at night and the presence of a warm layer of air aloft over the surface (the peculiar radiation conditions that can develop with a cloud cover, etc.) the normal pattern may be reversed and a layer of the atmosphere in which the temperature increases with height instead of decreases may develop. This particular situation is called an inversion of temperature and the layer through which the temperature increases with height is called an inversion layer.

One further aspect of the atmosphere must be recognized. Air is a compressible substance and air at any layer is subjected to a pressure determined by the weight of the column of air over it. Thus, if a parcel of air moves upward in the atmosphere, it will be going into regions of lower and lower pressure and therefore the parcel of air will expand. As the air expands, its temperature decreases. Thus, air that is forced to rise to regions of lower pressure will also decrease in temperature. The rate of decrease of temperature without condensation is known as the dry adiabatic rate of cooling. This rate approximates 5.5°F/1000 ft.

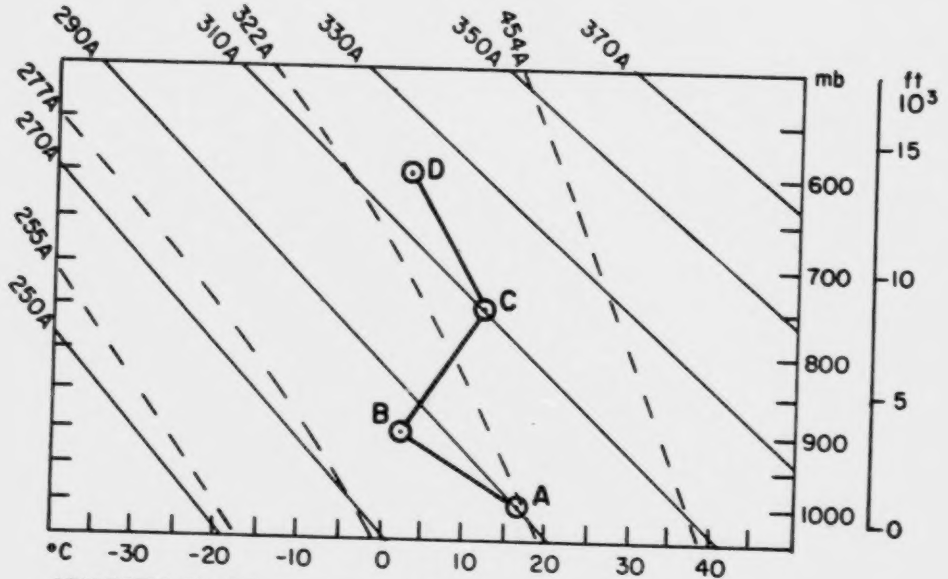
Comparison of the actual rate of temperature change with height with the dry adiabatic rate of temperature change will determine whether the air is convectively stable or unstable. Stability and instability in this case refer to the action of a parcel of air initially set in motion. If this parcel is set in motion upward and arrives at the next level of the air warmer than its surroundings, it will be lighter and more buoyant than the surroundings and want to continue to move upward. The atmosphere is said to be unstable. If, on the other hand, the parcel moving upward arrives at the next layer and is colder than its surroundings it will be heavier or more dense than its surroundings and tend to move back towards its starting place. The atmosphere is said to be stable since its temperature condition tends to resist the vertical upward movement of moving air parcels.

Figure 2 is part of a standard temperature-height diagram (called an adiabatic chart) which illustrates these relations more clearly. Height is given in the vertical in millibars of pressure. Temperature is on the horizontal, increasing to the right. The solid slanting lines are the dry adiabatic lapse rates (5.5°F/1000 ft). Curve ABCD is a profile of actual temperature versus height through the atmosphere measured by a temperature-measuring element taken aloft by a balloon. It can be seen that the segment AB has a greater decrease of temperature with height than the dry adiabatic, BC is a temperature inversion in which the temperature increases with height, and CD has a smaller temperature decrease with height than the dry adiabatic.

If a parcel of air at A is suddenly forced to rise to level B, it will cool by expansion at the dry adiabatic rate (assuming no condensation). Therefore, it will arrive at the level of B warmer than the air around it which is denoted by point B. Since it is warmer than the surrounding air at B it will be lighter and wish to continue rising. The layer AB therefore is called unstable. By definition, air layers through which the temperature change is greater than dry adiabatic are unstable and as a result of turbulent mixing of the air do not remain in existence very long.

If a parcel of air at point B or point C were suddenly set in motion upward to level C and D respectively, it is clear that both parcels (cooling dry adiabatically) would arrive at their next respective levels having temperatures somewhat colder than the surrounding air (denoted by the temperatures of points C and D). Thus, the parcels of air that started at B and C respectively would be more dense than the surroundings at levels C and D and want to return to the level from which they started. Air layers BC and CD are called stable but they differ markedly in their degree of stability. Layer BC being an inversion is strongly stable. The parcel of air starting at B and cooling dry

TEMPERATURE PROFILE WITH HEIGHT ILLUSTRATING STABLE AND UNSTABLE AIR LAYERS



ADIABATIC CHART

Ordinates are $p^{0.288}$ with pressure p in mb.
Abscissas are temperature in °C.
Solid sloping lines are dry adiabats at 20°K increments of potential temperature.
Broken sloping lines are pseudo-adiabats.

Figure 2

adiabatically as it moved toward C would be very much colder than its surroundings and therefore would tend to resist all movement away from B, while the parcel starting from C, being only slightly colder than its surroundings, would only weakly oppose the motion moving it away from C.

Significance of Turbulent Diffusion[1]

When contaminants are released at a particular point, the atmosphere acts as its own cleansing agent by transporting and diffusing such contaminants, thus reducing their concentrations. The ability of the atmosphere to dilute the contaminants depends mainly upon the following parameters: 1) the wind direction and velocity in a horizontal plane, 2) turbulence or wind shear in the vertical, and 3) the stability of the air as determined by the temperature distribution in the vertical direction. The last two are sufficiently related so that for practical purposes it is possible to consider just wind velocities and stability.

The basic theory would indicate that there is an inverse relation between wind speed and contamination at the ground; that is, the higher the wind velocity, the greater the intensity of turbulent diffusion, and the lower the concentration of contaminants at the ground. Observations tend to confirm this up to some limiting velocity.

Air flowing along the surface of the ground encounters a frictional resistance and is slowed down. The effect of this resistance is felt for hundreds of feet aloft. Within this zone of frictional influence, each successively higher layer of air moves faster than the one immediately beneath so that shearing stresses are set up between them, which result in the upward and downward displacement of small masses of air, each tending to preserve the horizontal velocity that it had previously. If a mass moves upward to a faster moving layer, in the process of mixing it will tend to retard the air in the higher layer. Similarly, a mass of air moving downward will tend to speed up the air in the lower layer. Thus, the difference in velocity between two adjacent levels tends to be equalized as horizontal momentum is transferred downward and ultimately dissipated at the ground. The tendency toward equalization of velocity depends on the rate of vertical mass interchange, or the intensity of turbulent mixing.

The greater the differences in velocity between adjacent layers, or the stronger the shear, the greater is the tendency for turbulence to develop and to reduce the shear. If there were no external influences helping to maintain the differences in wind velocity at different levels, turbulent mixing would eventually equalize the velocities in all levels and the air would move as a solid. However, since the supply of momentum in the upper air is practically inexhaustible, and since momentum is constantly being converted into heat and lost at the ground surface, wind velocities in different levels are never completely equalized. Thus, although turbulence tends to destroy shear, nevertheless the strongest mixing at a fixed level near the ground is associated with the strongest shear (Thornthwaite, 1943; Thornthwaite and Holzman, 1942).

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[1] This section is adapted from Thornthwaite, Mather, Davis, "Site Evaluations for Nuclear Reactors," Publications in Climatology, Volume 13, No. 1, 1960, pp. 12-16.

The dependence of vertical differences in velocity on the intensity of turbulent mixing is important because it enables us to determine the rate of mixing into the atmosphere by measuring the vertical gradient of wind velocity.

The influence of atmospheric stability on the vertical wind profile near the ground may be seen in a series of profiles that were obtained at Centerton, New Jersey, during several hours of February 25 and 26, 1957, reproduced in figure 3. They are 10-minute observations. The weather was mild and sunny at the beginning of the observation period, but during the evening the sky became cloudy and overcast with heavy rain beginning the next day. A few brief showers occurred during the night.

The data are plotted on a semilogarithmic scale; if the observations fell along straight lines, it would indicate that wind velocity varies as the logarithm of height. Actually, only one single series follows a straight line (line 55). The daytime observations usually plot along lines having concave curvature, while those made at night display a convex curvature. In this series, the observations made in the middle of the day on February 25 show strongest concave curvature (note curves 4, 5, 6, 7, and 12). The curvature shifted from concave to convex in the early evening between 1735 hr and 1907 hr. During the night, as the clouds thickened the curves approached straight lines and remained straight the next day during the rain. The difference between a sunny and rainy day is clearly shown by the first and last observations in the series (lines 4 and 88).

These observations suggest a reasonable physical picture of turbulent mixing in the atmosphere. When the thermal lapse rate is adiabatic, as for brief periods in the morning and again in the evening, the logarithmic law is fulfilled, and the coefficient of turbulent mixing is directly proportional to the wind speed. Turbulent mixing is mechanical only.

In the middle of the day, when thermal convection is active, convective turbulence is superimposed upon mechanical turbulence and the exchange coefficient becomes greater -- possibly much greater than is indicated by the standard equations. The concave curvature of the wind gradients is a consequence of this increase in the coefficient of turbulent mixing. As momentum is transported downward more actively, the tendency for differences in velocity in adjacent layers to be equalized increases, and the wind profile becomes more nearly vertical except very close to the ground surface.

At night when the ground, having been cooled by radiation, cools the adjacent air, the lowest layer of air becomes cooler than the above it and a stable lapse rate is created. The air next to the ground, being cooler, is denser than that above and, if moved mechanically upward into a fast moving layer, would tend to move down again instead of mixing with the air in the new environment. In this instance, the exchange coefficient becomes less and turbulent diffusion is strongly inhibited. Momentum is transported downward less actively, the tendency for velocity differences in adjacent layers to be equalized diminishes, and the velocity profile departs more than ever from the vertical except within a foot or two of the ground (Thornthwaite and others, 1943).

WIND PROFILES

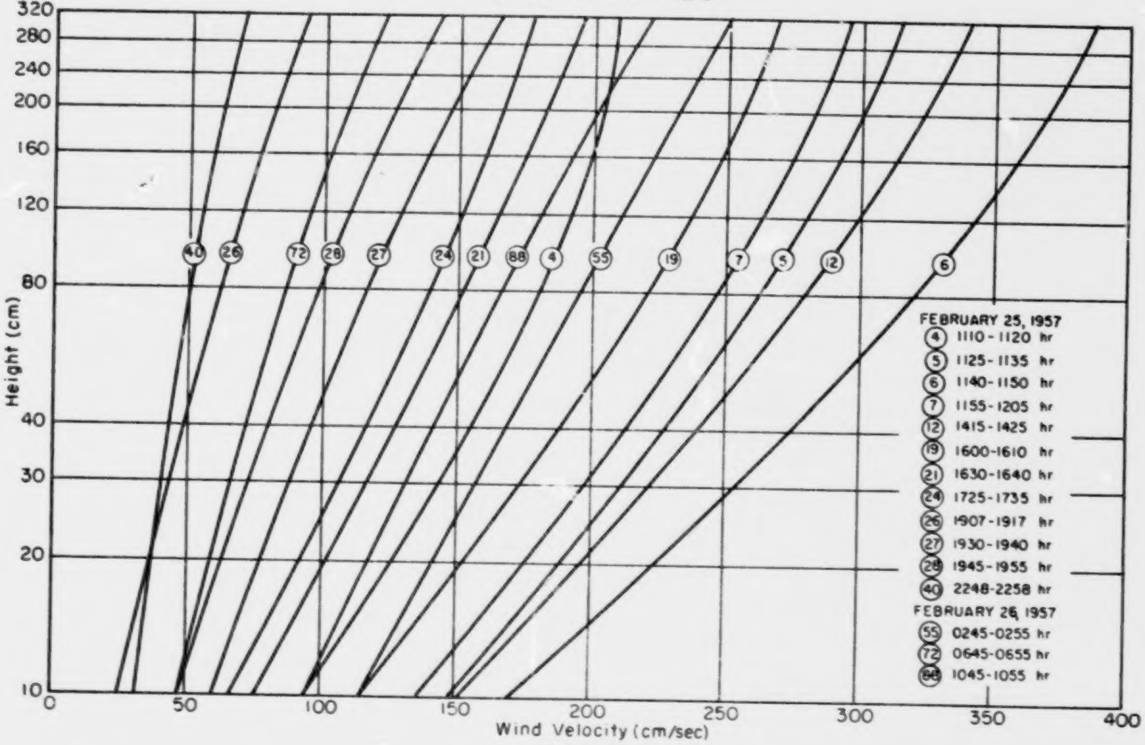

Figure 3

TEMPERATURE PROFILES

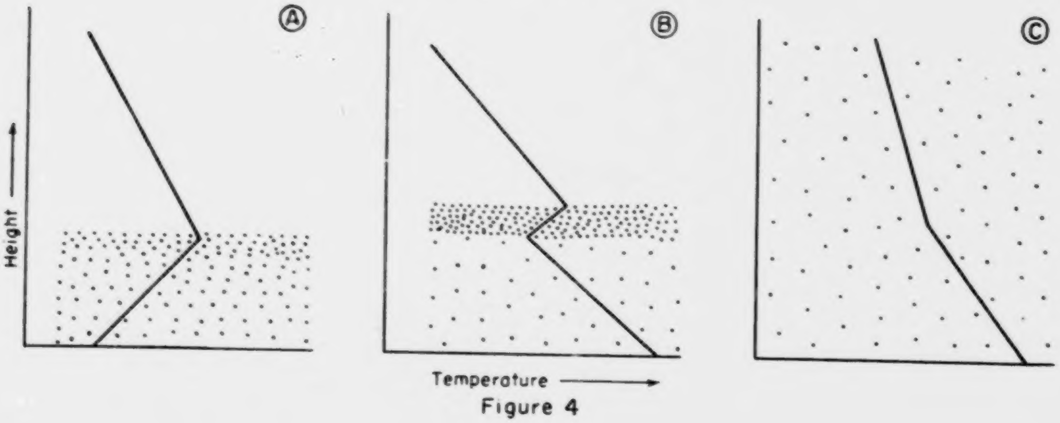
Ⓐ
Ⓑ
Ⓒ
Height
Temperature

Figure 4

The relationship between stability and concentrations of contaminants is direct; that is, the higher the degree of atmospheric stability the greater the concentration at the ground. With large lapse rates of temperature in the lower layers of the atmosphere, diffusion is rapid and ground concentrations low. With large temperature inversions, horizontal eddy diffusion is decreased and vertical eddy diffusion is practically eliminated, leading to greater concentrations of contaminants.

A complete mathematical analysis of diffusion processes which would allow quantitative calculations of concentrations is difficult because instantaneous velocities exhibit irregular and random fluctuations. Equations currently in use are based, in part, on statistical analysis and must necessarily include some constants which are empirical in nature. Probably the most widely accepted equations are those advanced by Sutton (1953). As applied to a continuous point source, they are as follows:

1) The concentration at the surface:

$$X_{x,y,z} = \left(\frac{2Q}{\pi C_y C_z \bar{u} x^{2-n}}\right) e^{-x^{n-2}\left(\frac{y^2}{C_y^2} + \frac{z^2}{C_z^2}\right)}$$

2) The maximum concentration at the surface:

$$X_m = \frac{2Q}{e \pi \bar{u} h^2} \left(\frac{C_z}{C_y}\right)$$

3) The distance from the foot of the stack at which the maximum concentration occurs:

$$d_m = \left(\frac{h^2}{C_z^2}\right)^{\frac{2}{2-n}}$$

The symbols in the above equations are defined as follows:

Q is the mass of contaminant emitted per unit time

C_y is the diffusion coefficient for the cross-wind direction

C_z is the diffusion coefficient for the vertical direction

$\bar{u}$ is the mean wind speed

x is the distance downwind from the source

y is the cross-wind distance

z is the vertical distance

h is the height of the stack

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n is a constant between zero and one relating to turbulence and is primarily related to the stability of the air.

e is the base of the Naperian logarithms, equal to 2.71828.

The Sutton equations are cited only to illustrate that in each case the existence of an inversion would exert an effect on one or more factors and hence would influence the results obtained by using the equations. For this reason and on the basis of numerous observations, it is generally agreed that the application of such equations for quantitative calculations gives good results except in cases where the atmosphere is very stable, or where a temperature inversion exists. Under inversion conditions, contaminants emitted from a stack may remain at the original level and drift for many miles in a very slowly widening horizontal band with little or no change in height or vertical thickness. When this condition occurs, the equations may overestimate ground concentrations. During periods of inversion breakup, when the atmosphere is changing from a stable to an unstable condition, ground concentrations may be underestimated by the Sutton equations. Sutton's equations or others developed by Pasquill are still used, however, to determine surface concentrations under stable or inversion conditions.

The effect of inversions is illuminated in figure 4. Radiative cooling during the night may produce a temperature inversion in the lowest few hundred feet of the atmosphere, restricting vertical motion and causing high concentrations of contaminants beneath the inversion as shown in figure 4A. During the first few hours after sunrise, insolation may break up this inversion with the layer of unstable air growing from the ground upwards. In this layer, turbulent diffusion occurs entirely downward, bringing concentrations of contaminants to the ground level, even at relatively large distances from the stack itself. This process is illustrated in figure 4B. These concentrations may persist for some time until the inversion is entirely broken up and turbulence throughout the layer causes rapid dilution, as shown in figure 4C.

In rural or suburban areas, ground concentrations are usually low when an inversion is first established. The existence of a nocturnal inversion may result in temporarily high concentrations of contaminants at the ground surface the following morning. The persistence of such an inversion may result in high ground concentrations for extended periods. In urban areas, of course, local conditions may result in high concentrations of contaminants either with or without inversion conditions.

Previous Studies of the Meteorology and Air Pollution in the Delaware Valley Area.

In October 1960, Davis completed a detailed study of "The Atmosphere over Philadelphia - Its Behavior and Its Contamination" under a contract with the City of Philadelphia. In it he attempted to investigate the weather influences on air pollution in Philadelphia itself and to determine whether or not periods of high atmospheric pollution might be anticipated on the basis of changing weather patterns. Because of the scope of this previous study and its obvious relationship to the present study, the results obtained by Davis will be referred to in the appropriate following sections.

Davis in his conclusions called for the collection of additional wind observations in order to define more clearly the low level wind flow patterns throughout the city especially under conditions of high pollution potential. At the same time, he noted the lack of any records of vertical distribution of temperature and called for the instrumenting of a radio or TV tower to provide observations, on a regular basis, of both temperature and wind with height.

The fact that additional wind and temperature measuring sites are now available is, therefore, one significant reason for the present study. In addition to being able to extend Davis' basic study and to expand on its scope with the new meteorologic data, the coverage of the study has also been expanded to the 11-county area around Philadelphia since conditions in any part of the Delaware Valley basin will contribute to the pollution potential in other parts of the basin.

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CHAPTER II. LOCATION OF METEOROLOGICAL AND AIR QUALITY OBSERVING STATIONS

One important aspect of the present study has been a survey of available meteorological and air monitoring stations in the Delaware Valley area and an evaluation of the current network in relation to the needs of air resources management in the basin. Because of year to year changes in station operation, it is difficult to obtain a clear picture of the actual observing network in the Valley area. Some stations are maintained for only a short period of time and then terminated while other long-term stations move to new locations. Thus, to obtain a realistic picture of the general availability and density of data, it was decided that the sampling network for one particular year, 1965, should be considered. Our evaluation will be made on the basis of information available for that one time period. Changes in station location in earlier or later years should not unduly change our conclusions based on 1965. A significant increase or decrease in the number of observing stations would, however, influence our present evaluations.

The primary source of meteorological observations in the Valley area is the U. S. Weather Bureau. There are several different types of Weather Bureau observation networks. First there is the cooperative observing network which supplies observations of maximum and minimum temperature and total precipitation once a day. These observations form the backbone of our climatic knowledge but, of course, the data are not particularly useful for the purposes of air pollution studies.

In addition to the cooperative temperature and precipitation stations, there are other stations that provide precipitation only. Since precipitation varies more than does temperature there is a need for additional point observations to permit a better understanding of the geographic distribution of precipitation.

A third group of observing stations involve those making hourly observations of wind speed and direction and of temperature and precipitation. These observations are taken at a relatively small number of so-called first-order observing stations located primarily at large airports.

The U. S. Weather Bureau maintains no stations in the Delaware Valley area to measure the distribution of temperature, wind, pressure, and humidity with height. These stations (radiosonde stations) are located at Washington, Pittsburgh, and New York just outside the Delaware Valley area.

In addition to the different Weather Bureau stations in the area, weather observations are also being taken by several other groups. Included among these are 1) state, county, or municipal groups; 2) utilities or industrial organizations; 3) military installations; and 4) private research or academic institutions.

Observations taken by state, county, or municipal groups include those taken at the six incinerator sites in the city of Philadelphia itself, the observations taken at the New Jersey Department of Forestry observing towers (fire danger and fire weather records) or those associated with some of the

Air Quality Sampling Stations. Usually these observations are taken by individuals not trained in meteorology. The instruments may or may not be calibrated frequently and oftentimes the records are not read from the strip charts but are filed for a period of time on the charts before they are discarded. Since the observations are taken at a particular site such as an incinerator or a fire tower, the exposure is often not the best, or most representative, and instrumental errors can exist in the record. This is particularly true in the case of wind observations.

An increasing number of meteorological observations are being taken by industries and utilities for their own use. Though not generally available, many such records have been made available for use here through the kind cooperation of the industrial organizations. The meteorological observations that are usually taken are temperature, and wind velocity and direction. Many of the same problems which apply to the weather observations taken by state or municipal groups also exist in this case. Often the instruments are installed without proper meteorological supervision and operated by untrained personnel, and the records are not evaluated or the instruments recalibrated periodically. In many cases, strip charts of the records are filed unread until they are thrown away. As a result, many errors can be incorporated in the records without being recognized by the users (one case was found where the wind vane was stuck on the same direction for almost a month without being detected). Some of these industrial observations are quite useful while others are of more limited value. Thus in evaluating the records obtained by both state and local governmental agencies and by industry, great care has to be exercised to separate the biased or incorrect results from those taken by instruments well exposed and carefully calibrated.

Observations taken by military groups and by private research or academic institutions are usually useful because they are more often taken by trained personnel, and evaluated at the time the observations are made. The instruments are recalibrated periodically. Often, observations by research groups are not continued for a long period of time so that it may not be possible to obtain more than just a brief record for analysis, but the available records are usually good.

A fairly complete and careful survey, by personal visit, by correspondence, and by telephone, has been made of all groups which might possibly be making meteorological observations. Here, State Health officials have been very helpful in putting us in contact with industries and other groups known to be taking observations. Sites were visited and descriptions of the exposures were made to provide the information needed to evaluate the reliability of the record. The U. S. Weather Bureau and the Weather Bureau offices in the various first-order weather stations, the State Climatologists and the weather officers at the military bases in the area have all been cooperative in supplying the requested meteorological observations.

As a result of this detailed survey we have been able to draw up the following list of stations in the 11-county area (table 1a) and in the immediate area surrounding the study region (table 1b) at which meteorological observations were taken in 1965. The stations are listed alphabetically by county in the three states in our survey area.

Table 1

List of Meteorological and Air Quality Observation Stations
Delaware Valley Area, 1965

a) Stations in Study Area

County	Temperature & Precipitation	Precipitation Only	Wind Speed & Direction	Profile Observations	Air Quality
Pennsylvania					
Delaware	Marcus Hook	Chadds Ford	Marcus Hook (I)		
Bucks	George School Quakertown	Doylestown Neshaminy Falls Sellersville	Bristol (I)		Pipersville Warminster
Chester	Coatesville Devault Phoenixville West Chester West Grove	Glenmoore Honey Brook	Phoenixville (I)		Embreeville West Chester
Montgomery	Graterford Norristown Willow Grove	Conshohocken Palm	Willow Grove		Eagleville Sanatoga
Philadelphia City & County	Phila.-Drexel Inst. Phila.-Intern. AP	North Phila. AP Phila.-10th & Chestnut	North Phila. AP Phila.-Intern. AP Phila.-Domino & Umbrea G & Remona Del. & Wheatchief Del. & Spring Garden 51st & Grays Ave. 7th & Patterson Phila.-Pt. Breeze (I) Phila.-10th & Chestnut (I)	Phila.-WFIL-KYW Tower (wind, temp. up to 890 ft)	Phila.-500 S. Broad 3200 Frankford 1501 Lycoming Phila.-Franklin Inst.

Table 1
(continued)

a) Stations in Study Area (continued)

County	Temperature & Precipitation	Precipitation Only	Wind Speed & Direction	Profile Observations	Air Quality
Delaware					
Newcastle	Middletown Newark Wilmington-Porter Res. Wilmington-Newcastle AP		Wilmington-Newcastle AP Wilmington (north) (I)	Delaware City (I) (wind up to 250 ft)	Newark Wilmington
New Jersey					
Burlington	Burlington Chatsworth Indian Mills McGuire AFB Moorestown Pemberton	Bass River St. Forest Lumberton Marlton	Apple Pie Hill Batsto Burlington (I) McGuire AFB		Marlton Pemberton
Camden	Audubon	Pennsauken	Blue Anchor		
Gloucester	Glassboro		Paulsboro (I)		Glassboro
Mercer	Hightstown Trenton	Princeton	Mercer (I) Mercer County AP		Hamilton Princeton
Salem	Centerton Salem Woodstown	Canton			

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Table 1
(continued)

b) Stations in Surrounding Area.

Temperature & Precipitation	Wind Speed & Direction	Profile Observations	Air Quality
Pennsylvania			
Allentown Bechtelsville Lancaster Morgantown Reading	Allentown Reading		Allentown Bethlehem Lancaster Reading
Delaware			
Dover AFB	Dover AFB		
New Jersey			
Atlantic City Cape May Hammonton Lambertville Millville Seabrook Farms Shiloh	Millville Mizpah Plainsboro (I)	Atlantic City (wind) Lakehurst (wind, temp)	Bridgeton Jutland

Figure 5 is a map of the 11-county study area and its surroundings with each of the meteorological observing stations identified with the appropriate symbol indicating the type of observations being taken. It must be understood that not all of the meteorological factors that are measured are indicated but rather only those that are of some significance in the present study.

The map shows a very uniform and fairly dense network of cooperative observing stations (daily temperature and precipitation) maintained by the U. S. Weather Bureau. In all we were able to locate 29 stations from which such daily information could be obtained. The number of stations ranged from 5 stations in Burlington and Chester counties to only one station in Delaware, Gloucester, and Camden counties. These daily observing stations were supplemented by 15 other stations at which only precipitation was measured.

Wind information, of much greater importance in any study of air pollution potential, is available from 24 stations in the 11-county area. These stations provide hourly or three-hourly observations of wind speed and direction. On the surface this number of wind observing stations would seem to be sufficient to provide an excellent coverage over the study area. However, not all of these stations are of equal reliability nor is their distribution over the study area evenly spaced. Thus, if we say that Weather Bureau and military observing stations might be generally reliable while other wind observing stations must be more carefully checked for possible errors or bias, it becomes necessary to consider the distribution of the various categories of observing stations. Actually there were only 6 Weather Bureau or military observing stations within the 11-county area in 1965, and two of these were in Philadelphia County. The other four were in Montgomery, Newcastle, Burlington, and Mercer counties so that there are large areas of the study area without wind observations. Of the remaining 18 wind observing stations, 9 were maintained by industrial groups (and all but one of these appeared to provide a quite reasonable record) while 9 were maintained by state or municipal groups. Three of these stations were located at fire observing towers in Camden and Burlington county and the records were only of limited duration. No observations were available in certain months of the year. The other six stations were located at incinerator sites in the city of Philadelphia. Great care must be exercised in evaluating these records because of the proximity of stacks and other obstructions that would influence wind flow in the vicinity. The nine stations operated by state or municipal groups, therefore, have a much more limited usefulness and can only be included if the nature of the exposure and the completeness of the record is carefully understood.

Of the 24 wind observing sites, ten are located in Philadelphia County, none in Salem County and only one in each of Chester, Montgomery, Bucks, Delaware, Gloucester, and Camden counties. The distribution of wind observing stations is much less satisfactory than the distribution of temperature or precipitation stations.

Profile observations of temperature and wind in 1965 were available from only two towers (one 890 feet high and the other 250 feet high) in the area. Both are located in the immediate Delaware River Valley area, one in northwest Philadelphia and the other near Delaware City, Delaware. While the data are quite reliable and useful, additional observing stations would be most desirable.

Several very useful meteorological observing stations are available in the areas immediately surrounding the 11-county study area. Wind observing stations located at Lakehurst, Atlantic City, Millville, Dover, Allentown, and Reading operated by the Weather Bureau or military groups provide helpful and reliable information,while some balloon-measured wind data are available from both Atlantic City and Lakehurst, east of the study area.

Air quality monitoring stations were fairly well spaced over the 11-county area in 1965. All told, there were 13 stations at which suspended particulates were measured on 20 to 30 random days through the year. These stations also provided information on beta radioactivity on those same days as well as information on benzene soluble organics. In several years previous to 1965 certain of these stations had reported selected observations of nitrates, sulfates, and many other fractions such as lead, iron, arsenic, and cobalt but these observations were not taken in 1965.

There were three additional stations operated by the City of Philadelphia, Department of Health which provided daily records of suspended particulates and soiling index in the city itself. Two of these stations were in the northeastern part of the city and the third was just south of the center city area. The daily record from these three stations is most useful in trying to understand the significant day-to-day changes in air quality and in any attempt to relate these changes with meteorological factors.

There is one station in Philadelphia (at the Franklin Institute) which is part of the CAMP (Continuous Air Monitoring Program) observing network. This station provides, among other things, continuous data on sulfur dioxide, nitrogen dioxide, carbon monoxide, nitric oxide, total hydrocarbons, total oxidants, and soiling index.

The distribution of the air monitoring stations over the 11-county area is fairly good. No sampling stations were located in Delaware, Salem, or Camden counties in 1965. One station was located in Gloucester County while two were located in each of Newcastle, Chester, Montgomery, Bucks, Mercer, and Burlington counties. Four stations were found in Philadelphia County. Additional sampling sites outside the study area included Bridgeton and Jutland, New Jersey and Lancaster, Reading, Allentown, and Bethlehem in Pennsylvania.

The list of air monitoring stations is included in table 1 and the location of each of the stations is also shown on figure 5.

LOCATION OF METEOROLOGICAL AND AIR QUALITY SAMPLING STATIONS 1965

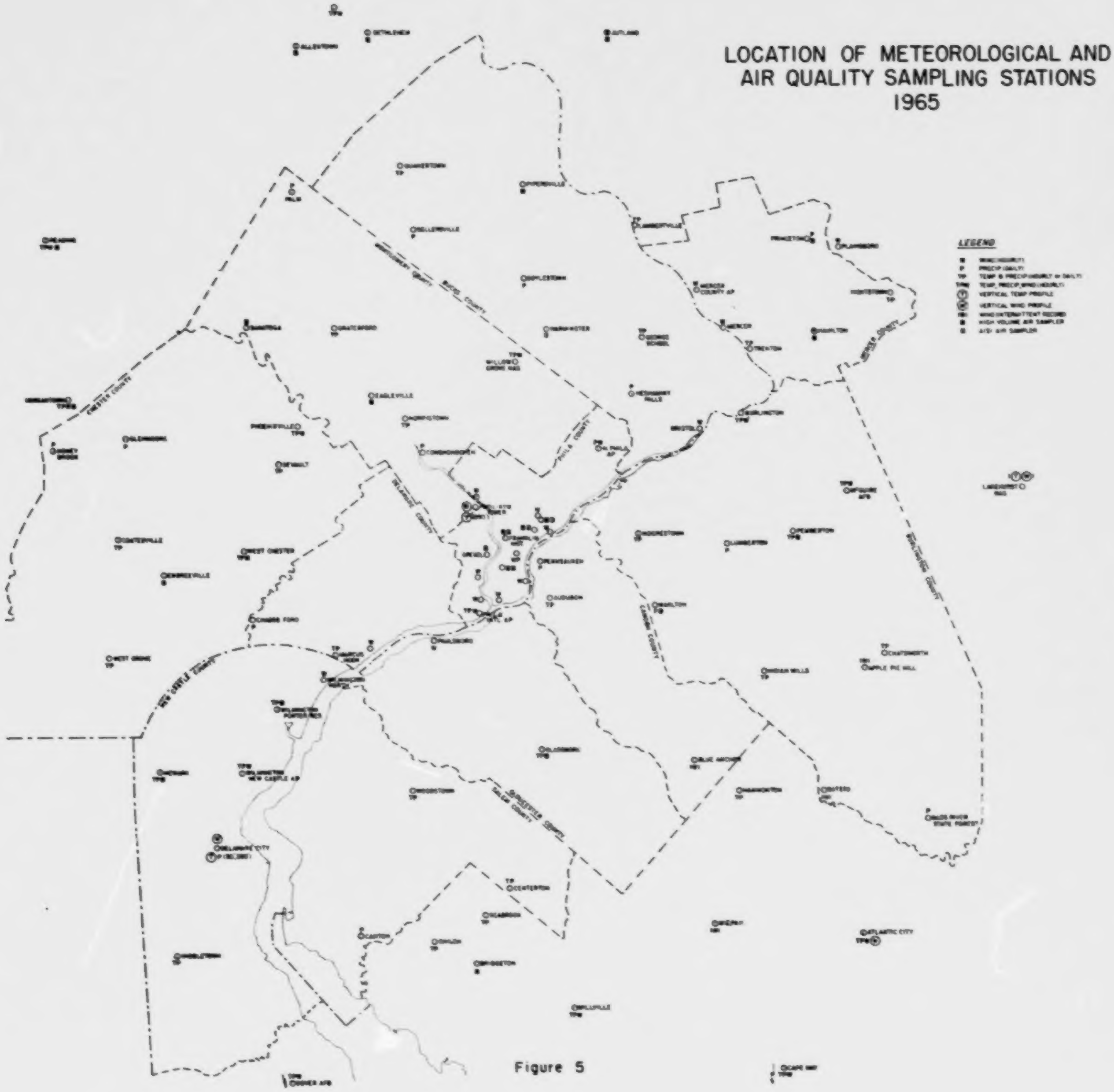

LEGEND
W WIND (HOURLY)
P PRECIP (DAILY)
TP TEMP & PRECIP (HOURLY or DAILY)
TPW TEMP, PRECIP, WIND (HOURLY)
VERTICAL TEMP PROFILE
VERTICAL WIND PROFILE
WIND INTERMITTENT RECORD
HIGH VOLUME AIR SAMPLER
AISI AIR SAMPLER
ALLENTOWN
BETHLEHEM
QUAKERTOWN
PIPERSVILLE
SELLERSVILLE
DOYLESTOWN
READING
LAMBERTVILLE
PRINCETON
MERCER COUNTY AP
TRENTON
WILLOW GROVE NAS
EAGLEVILLE
PHOENIXVILLE
COATESVILLE
WEST CHESTER
EMBREEVILLE
CHADDS FORD
WEST GROVE
MARCUS HOOK
BURLINGTON
MOORESTOWN
PEMBERTON
CHATSWORTH
INDIAN MILLS
APPLE PIE HILL
BLUE ANCHOR
HAMMONTON
WILMINGTON NEW CASTLE AP
NEWARK
DELAWARE CITY
MIDDLETOWN
WOODSTOWN
CENTERTON
BRIDGETON
MILLVILLE
ATLANTIC CITY
CAPE MAY
DOVER AFB
LAKEHURST NAS
CHESTER COUNTY
MONTGOMERY COUNTY
BUCKS COUNTY
PHILA COUNTY
DELAWARE COUNTY
NEW CASTLE COUNTY
MERCER COUNTY
BURLINGTON COUNTY
CAMDEN COUNTY
GLOUCESTER COUNTY
SALEM COUNTY

Figure 5

CHAPTER III. ANALYSIS OF WIND SPEED AND DIRECTION IN THE DELAWARE VALLEY

The direction of the wind and the speed with which it blows are undoubtedly the two most important factors influencing the movement and dispersal of any materials put into the atmosphere. Light winds result in slow movement and little mixing of atmospheric contaminants while winds from the same direction, for long periods of time, result in the steady downwind movement of materials from source to receptor without much opportunity for lateral mixing and spreading. Thus any study of atmospheric pollution potential must investigate in detail the wind speed and direction.

The previous chapter has provided an indication of the density and distribution of wind-observing stations over the study area as well as the degree of confidence which may be placed in the available data. While the wind observation network is not as complete as one would wish, the relatively flat topography in the 11-county study area imposes few restrictions on the free flow of air over the region so that the available data can be considered representative of fairly broad areas around each observing station. The existing density of wind observation stations does provide us with a relatively reliable picture of the flow over the whole basin.

Selected Wind Roses for 1965

In analyzing the wind pattern over the area it is not necessary or possible to include wind roses from all stations listed in table 1. Rather, data from only a selected number of stations are included for discussion purposes. Care has been taken in choosing the data to show the variety of conditions that can exist over the area as well as conditions that are representative of the wider region. Figures 6a through 6m show the monthly course of wind speed and direction at six selected stations in the Delaware Valley area as well as the annual totals. Four wind speed categories are used: calm, 1-3, 4-10, and >10 knots. The winds are plotted on a 16-point compass with each arrow indicating the frequency of wind in a 22½-degree wide angle, 11¼ degrees on each side of the indicated arrow. The length of the bar represents the percentage frequency of winds from that particular direction in each wind-speed range. It must be remembered that each of the bars points towards the center of the diagram and indicates that the wind is blowing from the direction toward the center. Thus, a wind arrow at an angle 45 degrees from the horizontal in the upper right-hand part of the wind rose means a northeast wind or a wind from the northeast blowing toward the southwest. The percentage of calms is given in the center of each wind rose. For conversion purposes, one knot equals 1.15 miles per hour.

The six stations, Allentown, Mercer, Phoenixville, Burlington, Marcus Hook, and Philadelphia, should be representative of conditions from north to south across the 11-county, Delaware Valley area. Two of the stations, Allentown and Philadelphia, are regular Weather Bureau observing stations with observations taken by meteorologically trained personnel. The exposures are excellent, and the observations can be considered to be quite reliable. The other four stations, Mercer, Phoenixville, Burlington, and Marcus Hook, are all industrial observation sites. From a careful study of the records, they appear to be reasonable although certain discrepancies between these records and those taken at Allentown and Philadelphia are undoubtedly due to instrumental or observing problems rather than differences in the real wind. These differences will be pointed out in the course of the discussion.

The annual wind rose at each of the six stations for 1965 (figure 6a) indicates, as expected, a predominance of winds from the westerly direction in the Delaware Valley area. At Allentown, the winds are almost equally from the northwest and southwest quadrants while at Philadelphia the southwest quadrant prevails. Phoenixville is much like Allentown with the northwest and southwest quadrants both equally favored, but the large number of light winds and calms, 22.9 percent as compared to 1.5 at Philadelphia, and 9.4 at Allentown, shows that the instrument was not as responsive to winds at Phoenixville as at Allentown or Philadelphia. Wind directions do seem quite consistent in spite of the lower velocities, however.

The Marcus Hook observations are interesting because of the predominance of southwesterly winds. Winds are from the southwest almost 25 percent of the time. The next most frequent direction is from the north with about 12 percent. While southwest is a prevailing direction as shown by the Philadelphia observations, the extreme percentage from southwest, coupled with the high percentage from north, casts some doubt on the representativeness of the exposure of the instrument or its operating characteristics. While the Delaware River nearby does run in a northeast-southwest direction past Marcus Hook, the topography is so flat that one might question whether the presence of the river would be sufficient to cause such a marked orientation of the winds themselves.

The Burlington wind rose seems to be quite similar to the Allentown or Philadelphia wind roses although the annual rose does show more south-southwest winds as opposed to southwest or west-southwest winds at the other stations. The wind rose from Mercer is also interesting because of the lack of certain wind directions. At Mercer, there is a very low percentage of winds from the northwest, a direction quite favored at the other observing sites. This low value of wind from the northwest shows up in every month of the year and must be the result of a local exposure problem.

The pattern of change in wind directions and velocities through 1965, shown on figures 6b through 6m, is much as one would expect in this area. In the winter season, illustrated by January, February, and March, there is a greater frequency of high winds (long shaded bars on the diagram). Wind directions favor the north to northwest quadrant. This is especially evident in the January wind roses with even the northeast quadrant being favored at all stations except Phoenixville.

Wind velocity decreases in the spring of the year, and the prevailing direction begins to shift from northwest to west. In April, at Marcus Hook, there is a large percentage of winds from both the southwest and northeast directions with the most frequent direction being north. This pattern is difficult to explain. Burlington and Philadelphia still show prevailing directions from north to northwest in the April, 1965, observations. May, 1965, had very strong winds from the southwest at all of the six observing sites. The

WIND ROSES, DELAWARE VALLEY
ANNUAL - 1965

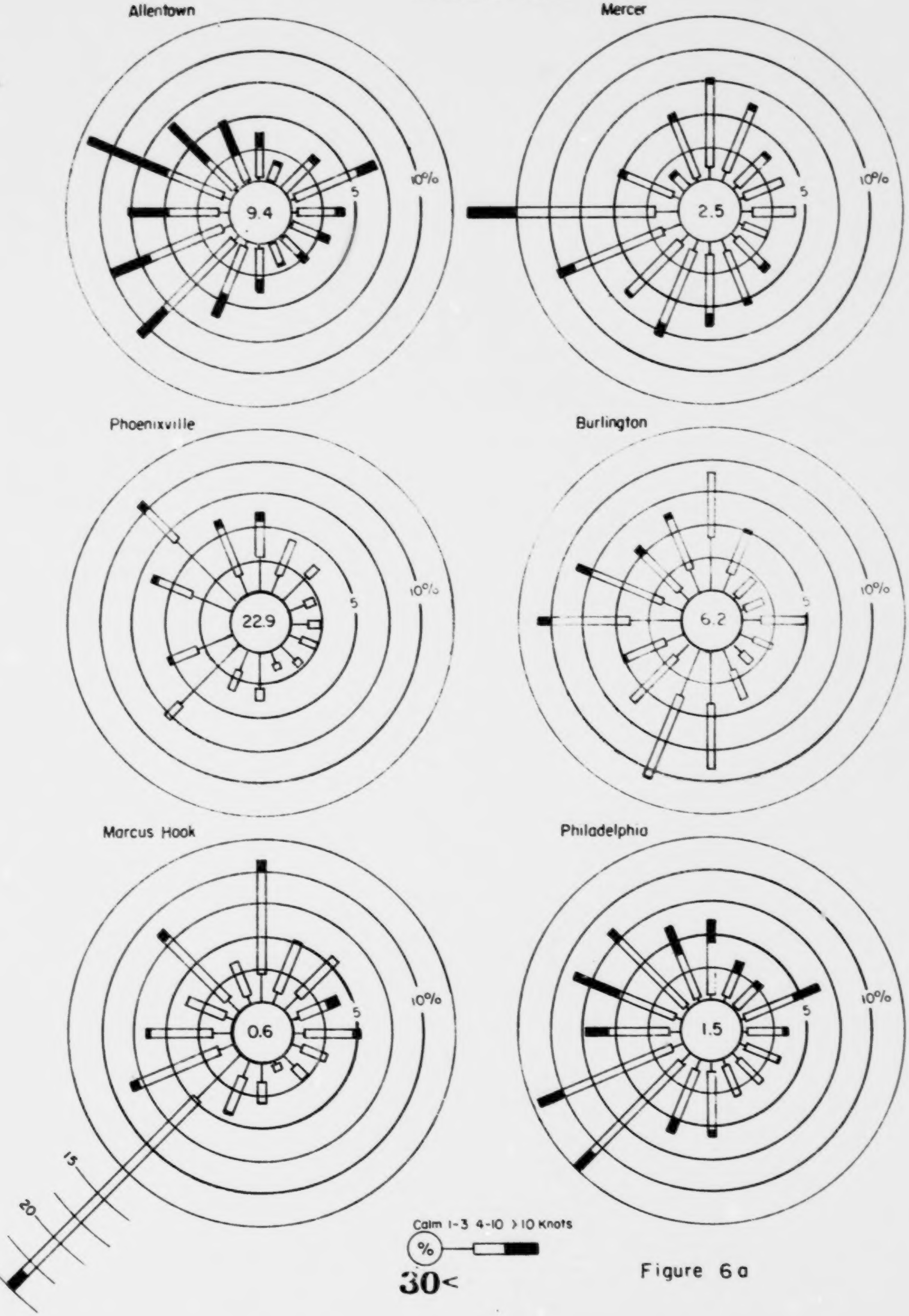


Figure 6a

WIND ROSES, DELAWARE VALLEY
JANUARY, 1965

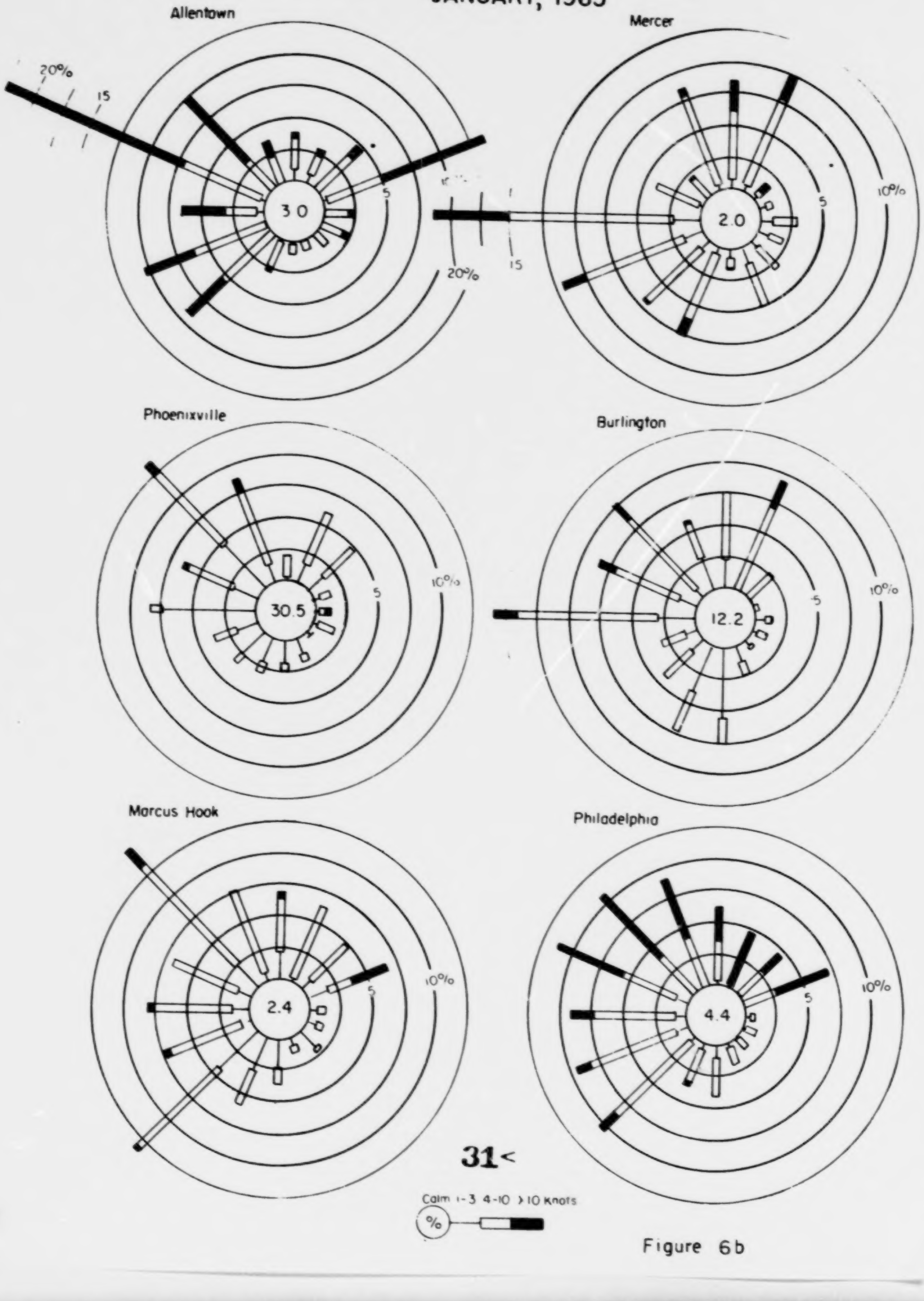


Figure 6b

WIND ROSES, DELAWARE VALLEY
FEBRUARY 1965

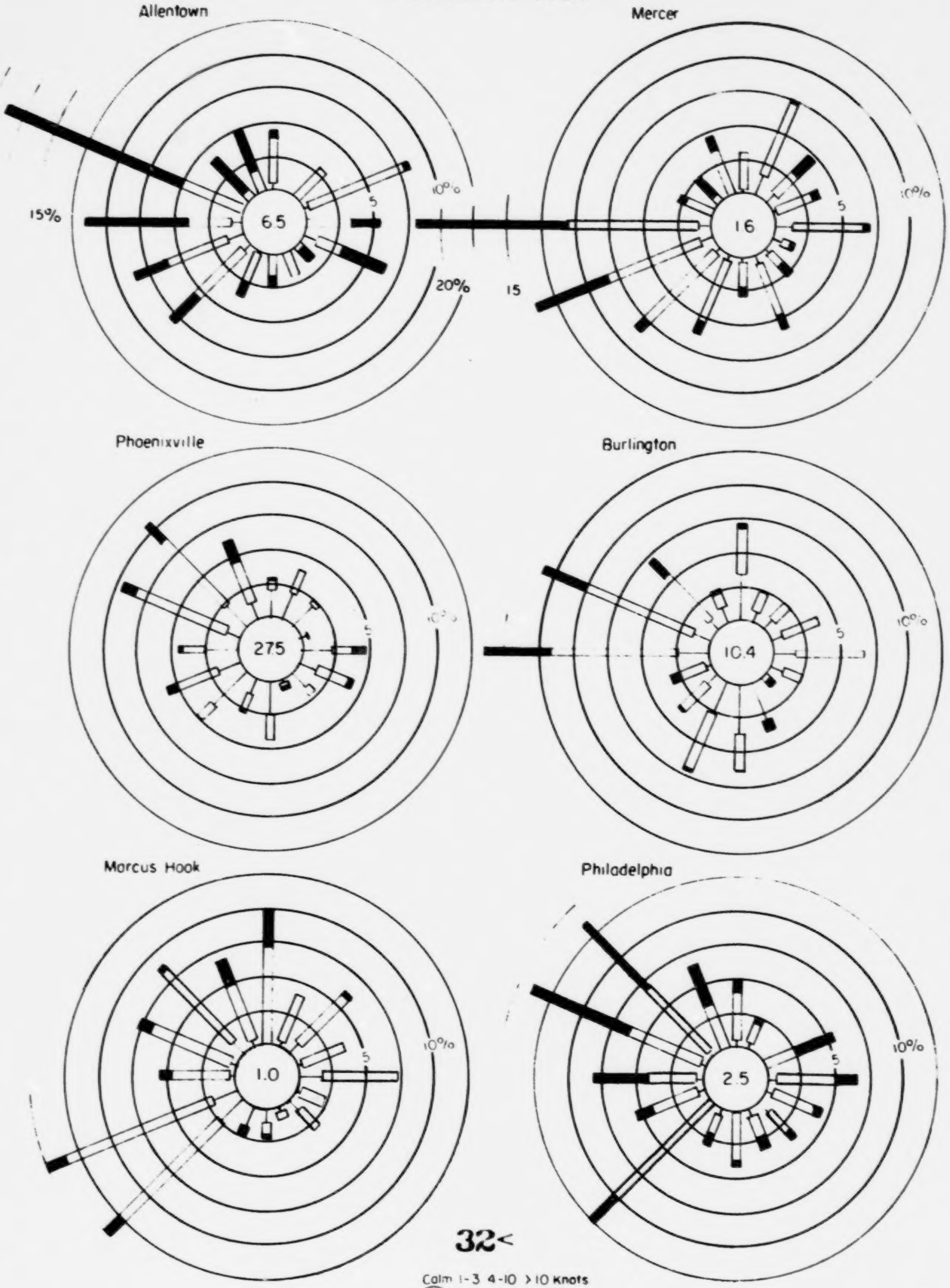
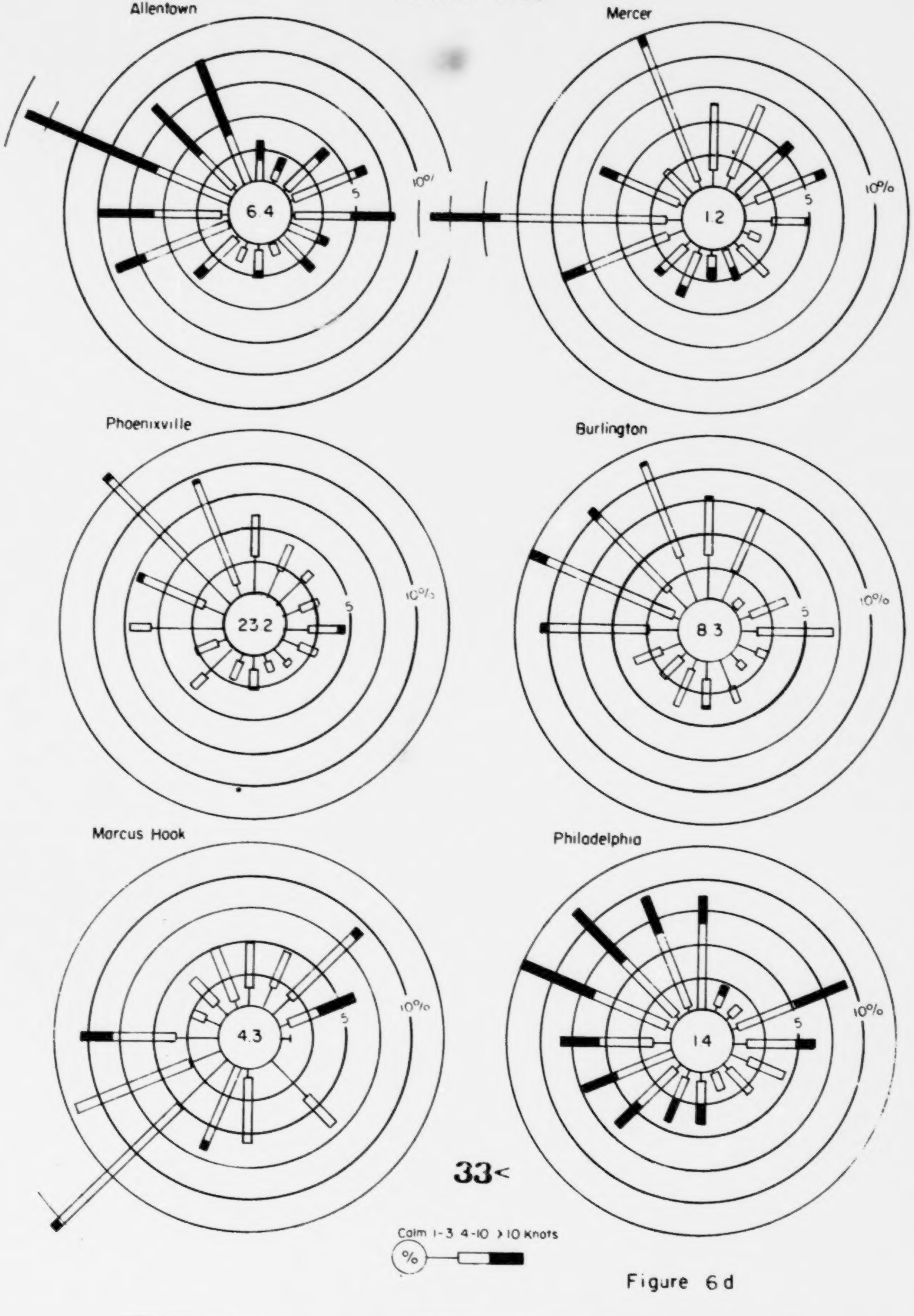


Figure 6c

WIND ROSES, DELAWARE VALLEY
MARCH 1965


Allentown

Mercer

Phoenixville

Burlington

Marcus Hook

Philadelphia

Figure 6d

WIND ROSES, DELAWARE VALLEY
APRIL 1965

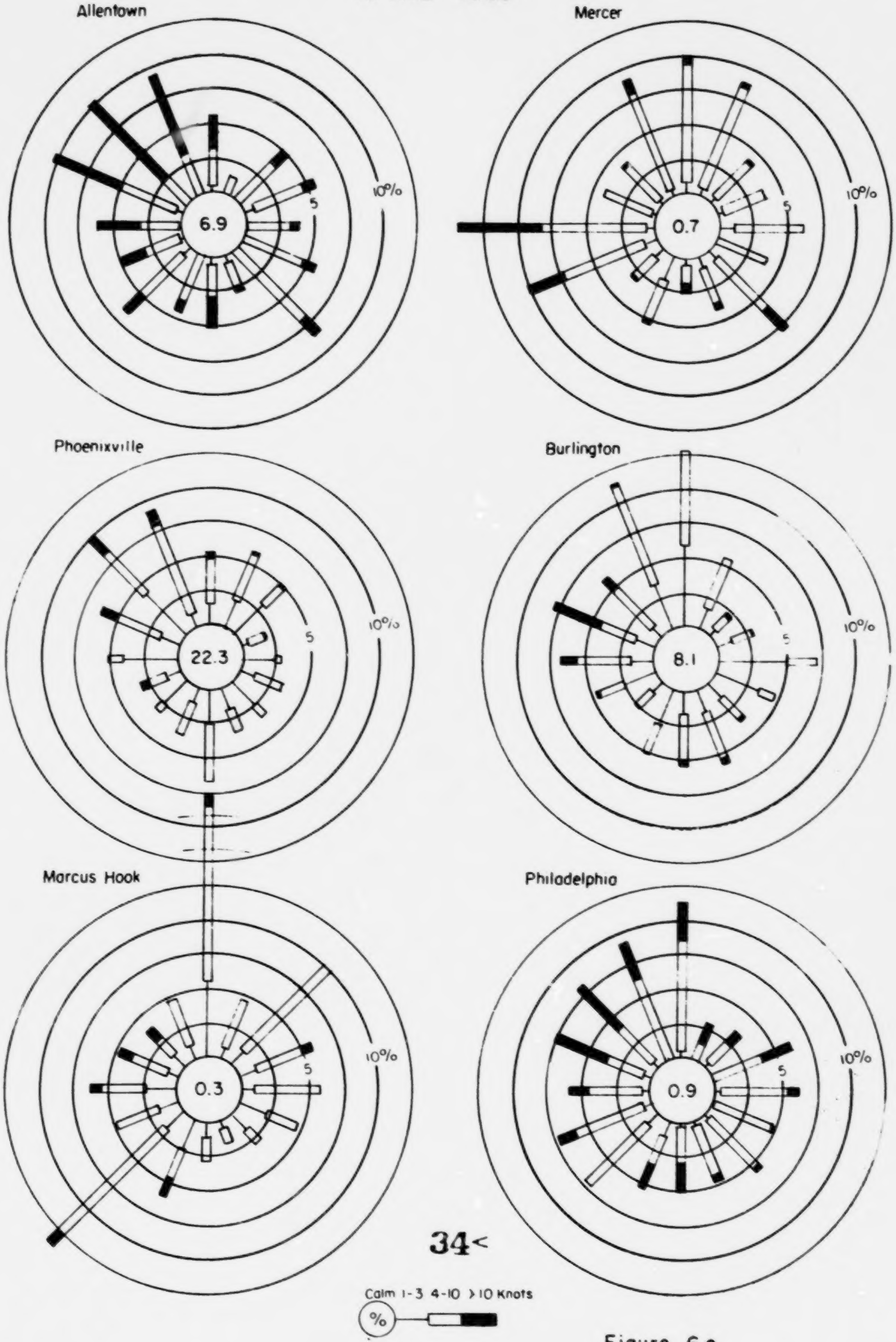


Figure 6e

WIND ROSES, DELAWARE VALLEY
MAY 1965

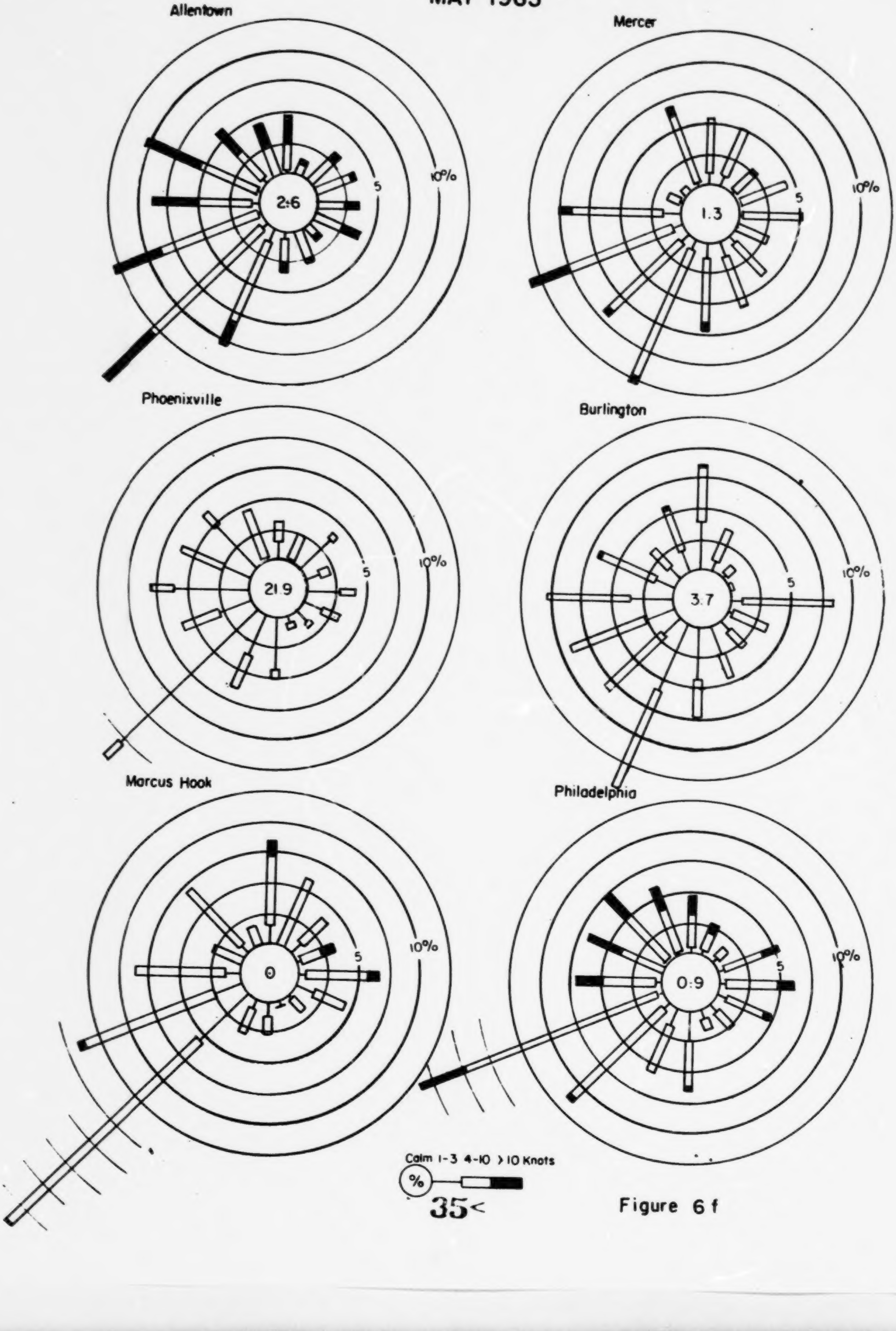


Figure 6 f

WIND ROSES, DELAWARE VALLEY
JUNE 1965

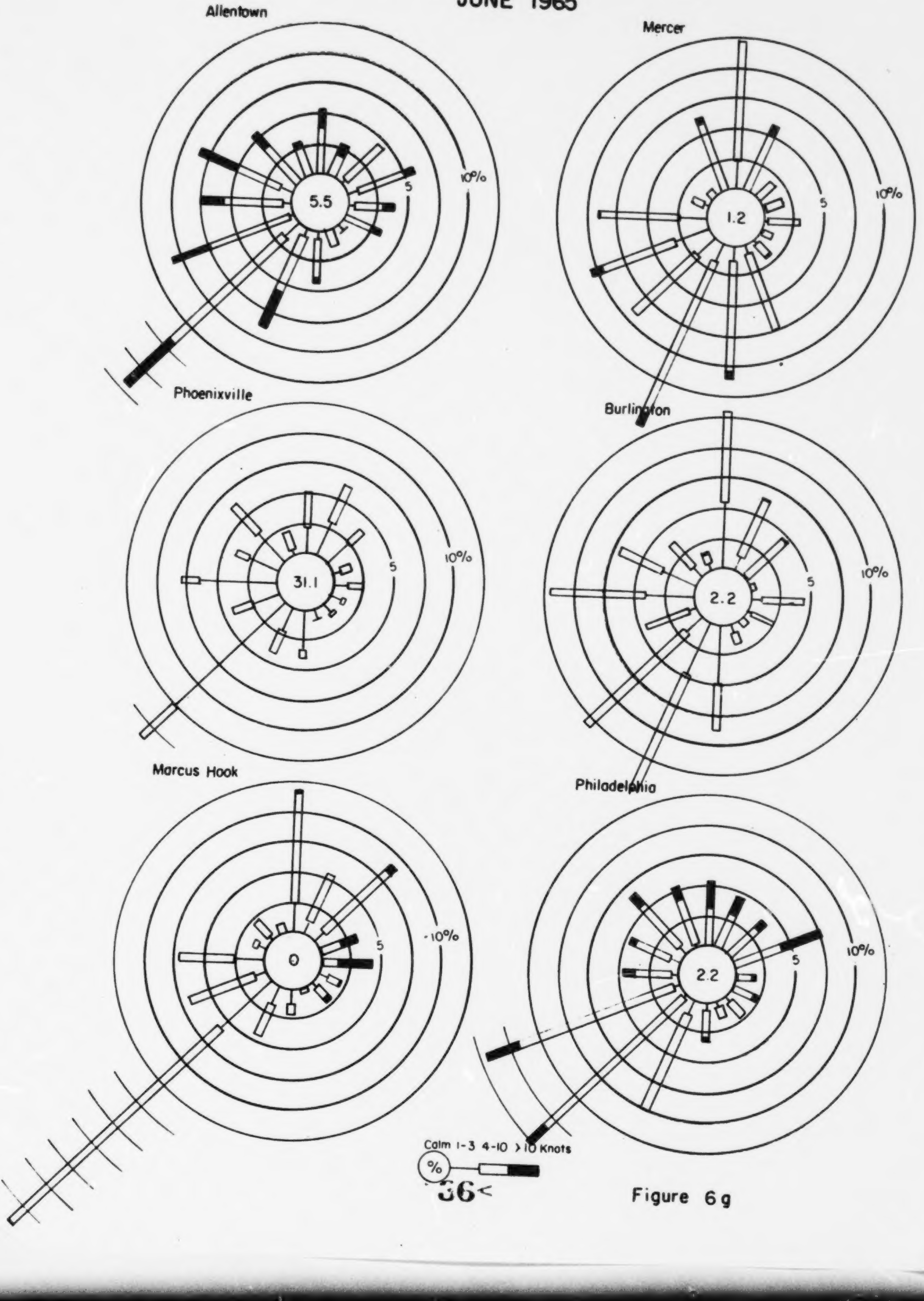


Figure 6g

WIND ROSES, DELAWARE VALLEY
JULY 1965

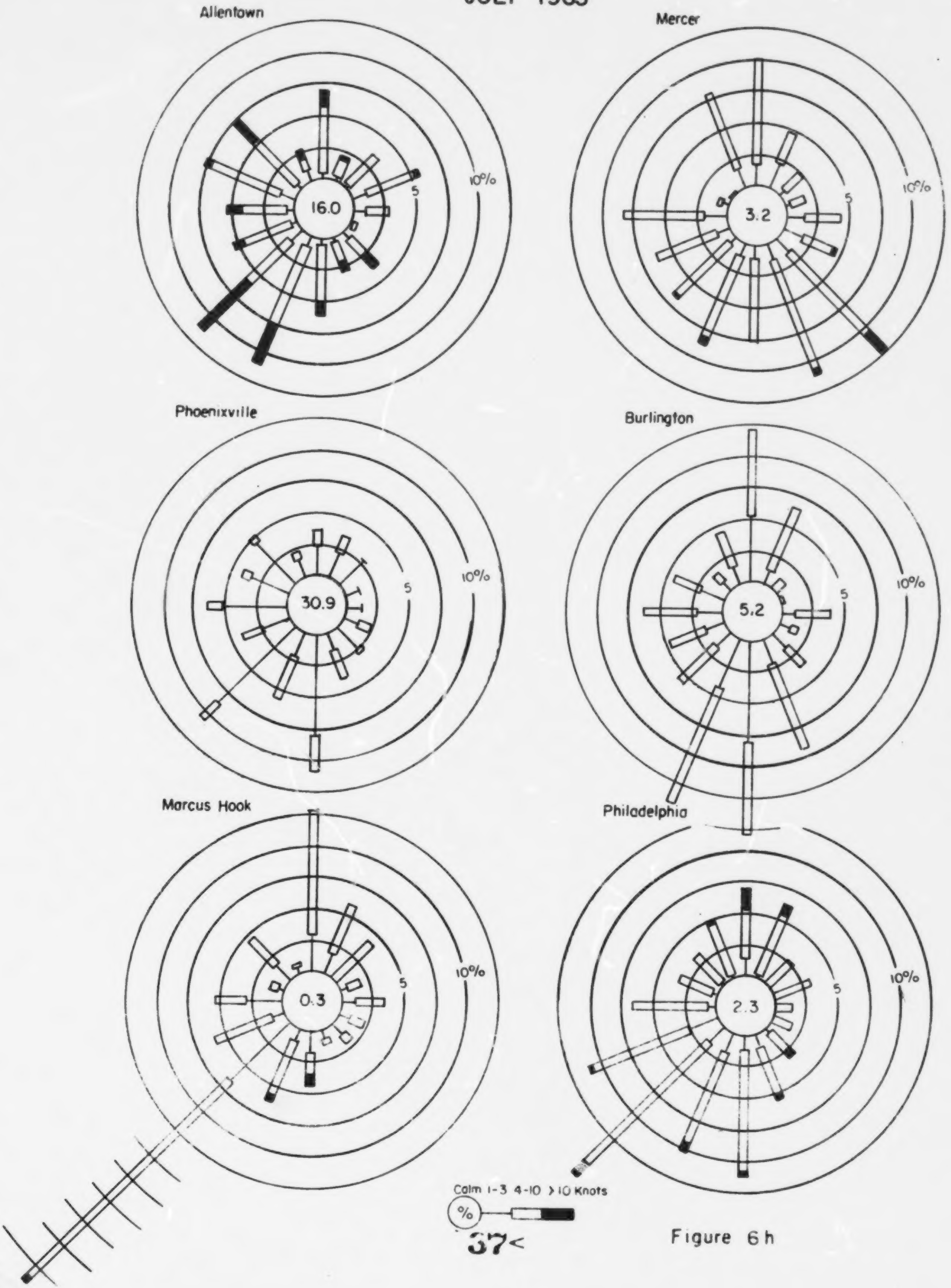


Figure 6h

WIND ROSES, DELAWARE VALLEY
AUGUST 1965

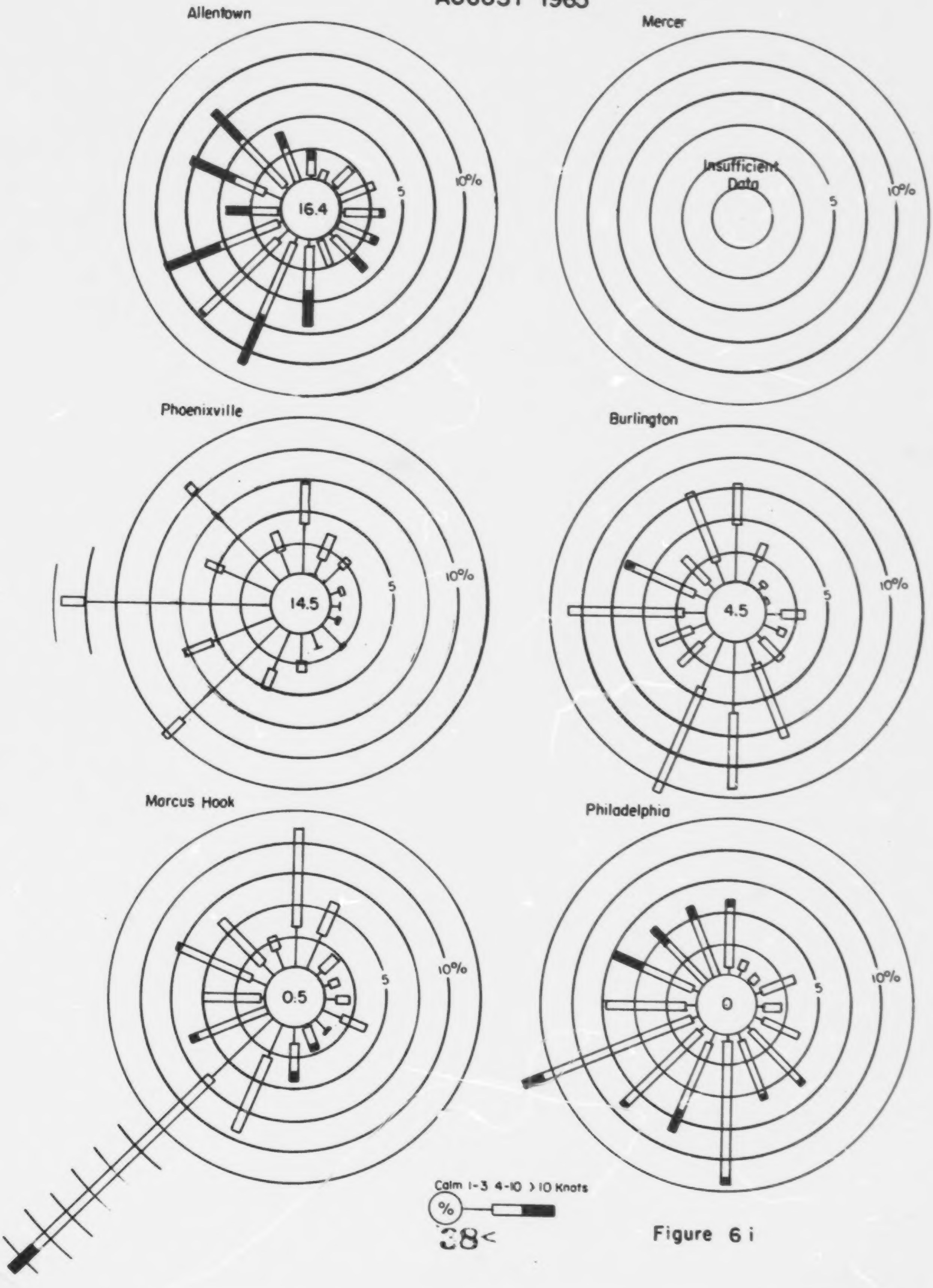


Figure 6 i

WIND ROSES, DELAWARE VALLEY
SEPTEMBER 1965

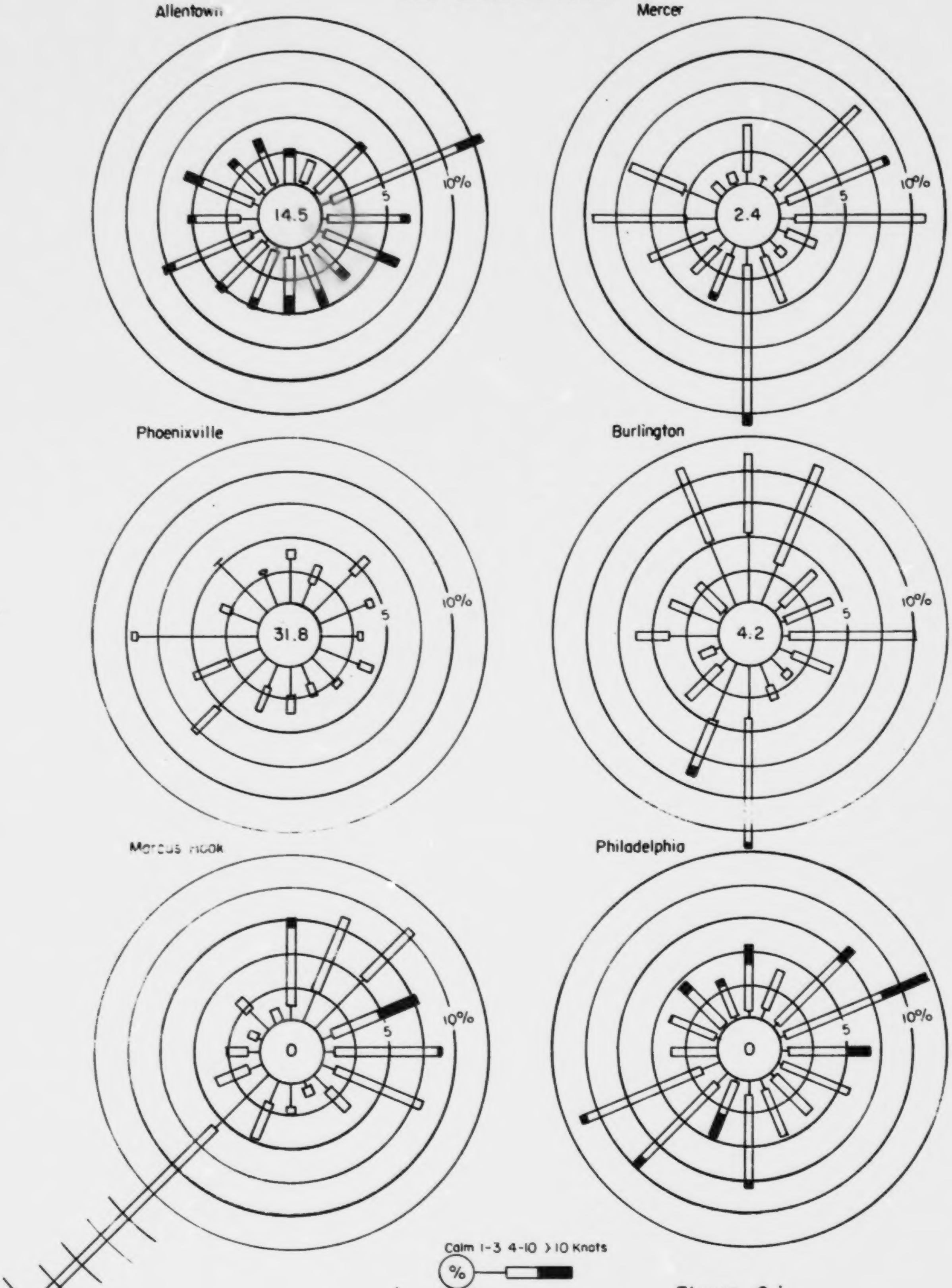


Figure 6 j

WIND ROSES, DELAWARE VALLEY
OCTOBER 1965

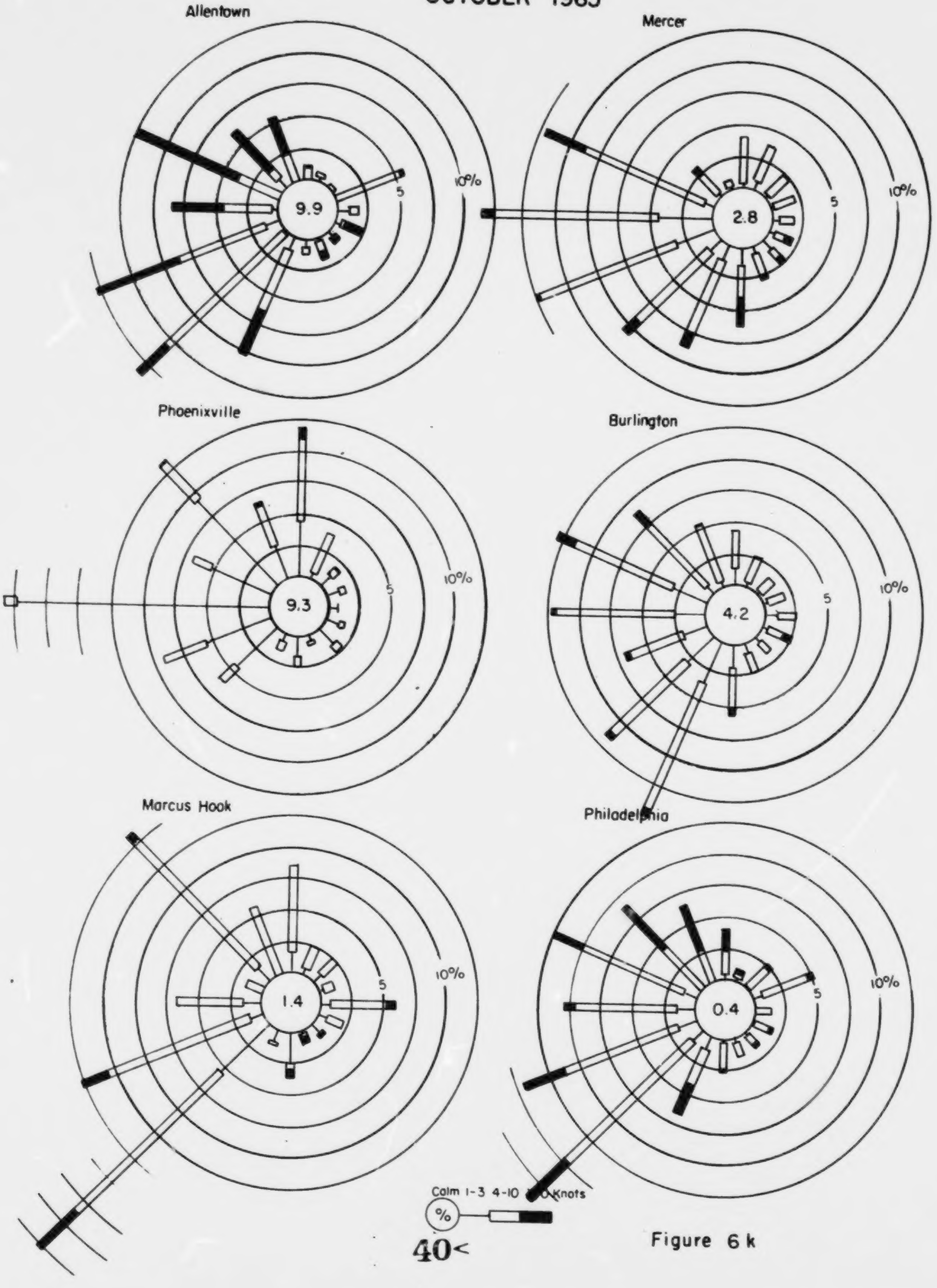


Figure 6 k

WIND ROSES, DELAWARE VALLEY
NOVEMBER 1965

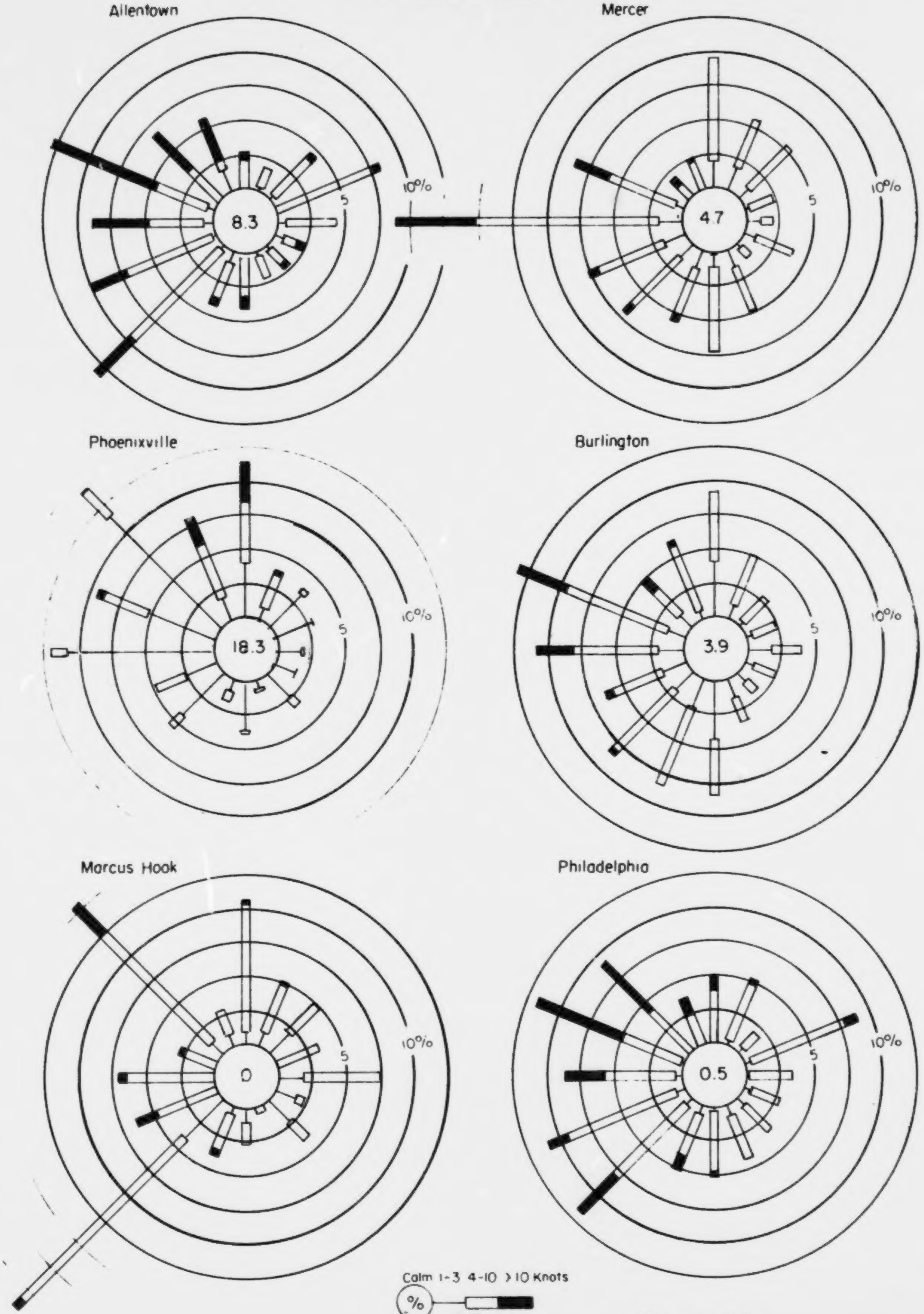


Figure 61

WIND ROSES, DELAWARE VALLEY
DECEMBER 1965

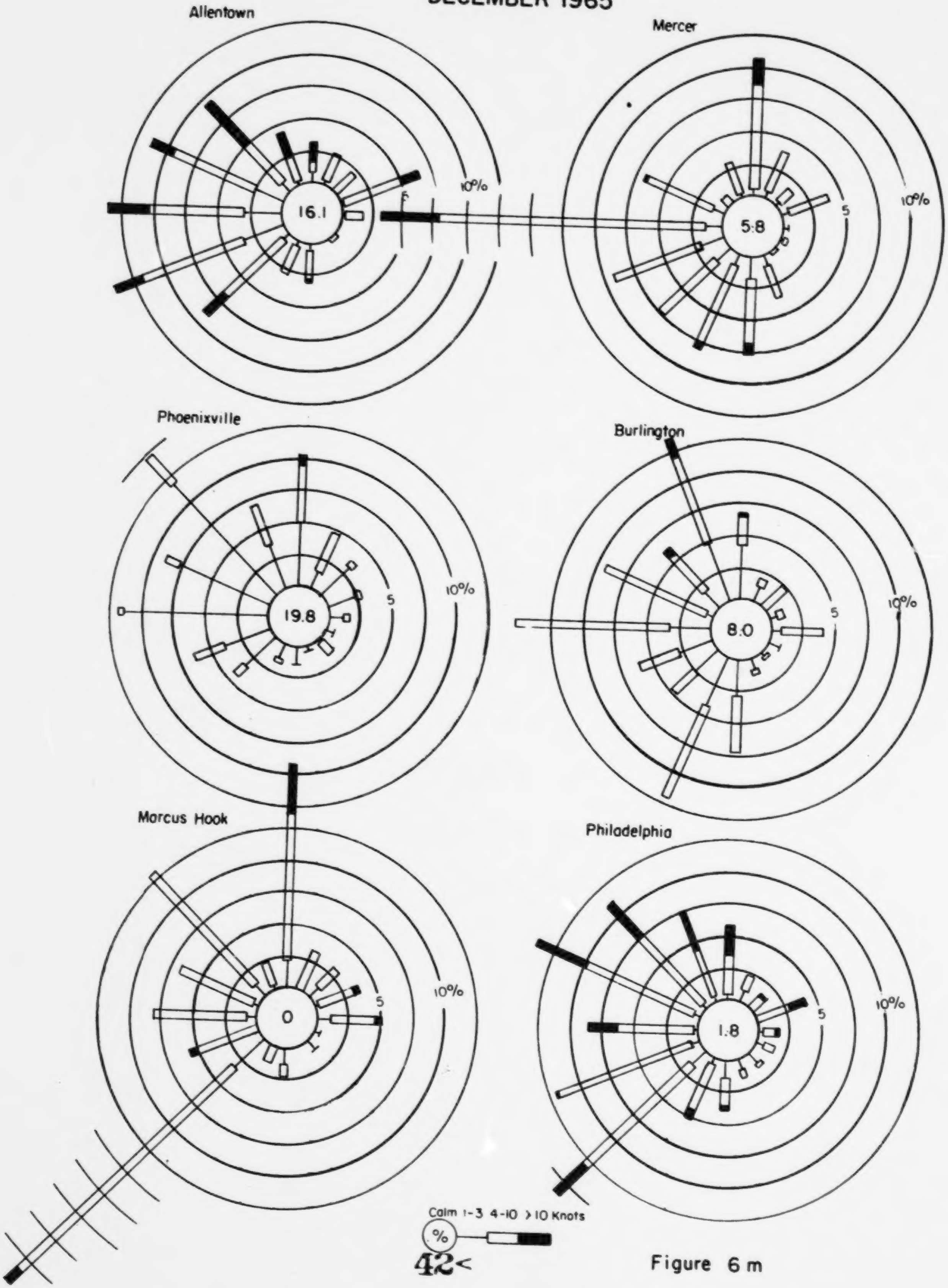


Figure 6 m

frequencies were accentuated at Marcus Hook but southwest winds were found at all sites. June was quite similar with the southwesterly direction prevailing. At Marcus Hook, almost 40 percent of the winds came from the southwest.

The summer season, illustrated by July, shows much lighter winds at most of the stations. Only Allentown has any appreciable winds over 10 knots. The prevailing wind direction is southwest as expected with the southeast direction also favored at Mercer. Marcus Hook and Burlington still had a large number of winds from the north. The August wind roses were quite similar to those in July.

September, 1965, witnessed an increase in the winds from the northeast and east with the east-northeast direction being most favored at Allentown and Philadelphia. While southwest directions were still recorded at Marcus Hook, northeast winds were also quite frequent. In October, the winds shifted into the westerly directions, being primarily west at Phoenixville and Mercer and southwest at the other stations. The westerly pattern prevailed in November and December also with Marcus Hook showing a large number of southwest winds and Mercer a large number of straight west winds. Phoenixville emphasized the northwesterly quadrant while Allentown, Philadelphia, and Burlington had winds quite uniformly from all directions between northwest and southwest.

Comparison of 1965 Wind Roses with Average Long-Term Conditions

Figures 6a through 6m show the monthly and annual wind roses for six selected stations in the Delaware Valley area for the year 1965. The question whether these 1965 wind roses are representative of the long-term average wind patterns in the Delaware Valley area must now be asked. To provide a partial answer to this question, the 1965 monthly and annual wind roses for Wilmington, Delaware have been compared in figures 7a through 7e with the long-term average monthly and annual wind roses from the same station. The long-term average wind rose is based on data from August 1942 through February 1946 and January 1948 through August 1955 (a little over 11 years of data). The Wilmington station is operated by the U. S. Weather Bureau and its records can be considered quite reliable. Comparing the 1965 wind roses for Wilmington with those given in figures 6a through 6m for the six other stations in the Delaware Valley area, we can see that the Wilmington wind roses are quite similar to those found at Allentown or Philadelphia. The prevailing wind at Wilmington, on an annual basis, is west-northwest which is the same direction as at Allentown although it is west-southwest in Philadelphia. The wind roses for Wilmington do not look at all like the Marcus Hook wind roses, a station that is relatively only a few miles away, and so it might again lead us to question the representativeness of the Marcus Hook data.

Comparing the long-term annual wind rose for Wilmington with that found in 1965, we can see little difference. The number of calms is higher on the long-term average basis than in 1965, and the most frequent wind is northwest on the long-term basis and west-northwest in 1965, but these are minor differences. One can say that 1965, on the average, was entirely similar to the long-term average. As one considers individual months of the year, however, certain differences can be noticed. Figures 7b through 7e show the wind roses by months, for Wilmington, on the long-term basis and for 1965. In January, February, and March, there is very little difference between the 1965 results and the long-term average except for the higher percentage of winds from the west-northwest. This difference would not seem to be significant.

In the spring months of the year - April, May, and June - a slight difference between the 1965 observations and the long-term average observations becomes apparent. While the long-term average monthly observations still favor the northwesterly direction with an increasing number of winds from the south and southeast, the 1965, Wilmington observations show a very high value of west-northwest winds in April shifting to a high value of southwest winds in both May and June. June, in fact, experiences the greatest number of winds from south-southwest with another high frequency of winds from north-northeast (exactly the opposite direction). This is not found in the long-term average picture for June. This shift to the southwesterly directions in May and June was also noticed in the six stations given in figures 6f and 6g and was evidently unique to 1965.

Two differences between 1965 and the long-term average picture were found in the summer months of July, August, and September. First, the number of calms were considerably less in 1965 than the long-term average. There were less than one percent calms in each summer month in 1965 while calms were experienced on the long-term average anywhere from 6 to 9 percent of the time. With fewer calms, this meant that the frequency of winds from different directions could be higher in 1965 than on the long-term average. On the basis of long-term average monthly values, no one wind direction predominates in the summer at Wilmington. All directions from northwest around to south-southeast experience about the same frequencies of winds through the summer months. South is favored in all three months but so is northwest. For July 1965, the south direction was most favored and there was a large percentage of moderate to strong winds. In fact, hardly any low velocity winds (between 1 and 3 knots) were found in July or August at Wilmington in 1965, although a reasonable number of such low wind speeds did occur on the long-term basis. Both July and August had fewer winds from the northeasterly quadrant in 1965, but considerably more winds from the south-southwest and west-northwest sectors. September, 1965, was quite different from the normal September, with a high percentage of winds from the east-northeast and from the east. South and south-southwest were also favored directions in September.

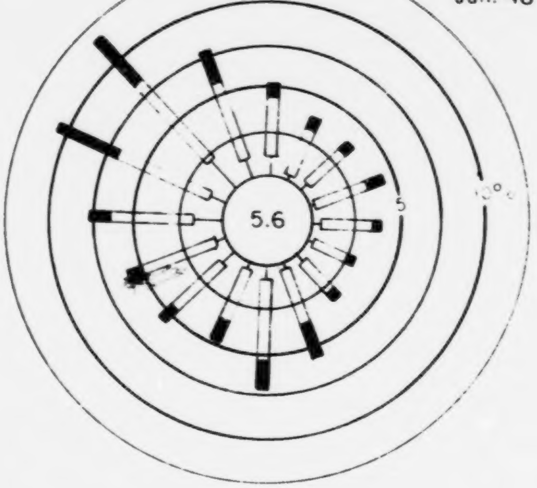
The fall months, October, November, and December of 1965, agree more closely with the long-term average monthly picture. While October has a large number of winds from the southwest and west-southwest which were not found in the long-term picture, the most frequent wind is from the northwest as in the case of the long-term average values. November and December, 1965, both have most frequent winds from the west to northwest sector, and this is found in the long-term average picture also.

We might conclude that 1965 was reasonably representative of the long-term average picture during the winter and early spring and also during the late fall months. During the summer of 1965, winds were from the southwest early in the summer season and from the south in the late summer period more than usual, with September 1965 noticing a very high number of winds from the east-northeast. This high value of east-northeast winds in September was also found in Allentown and Philadelphia and evidently resulted from the general circulation patterns existing in the area during that particular month.

COMPARISON OF MONTHLY AND ANNUAL WIND ROSES WILMINGTON, DELAWARE, BASED ON LONG-TERM AVERAGES AND DATA FROM 1965

LONG TERM

Aug. '42 - Feb. '46
Jan. '48 - Aug. '55



ANNUAL DATA

1965

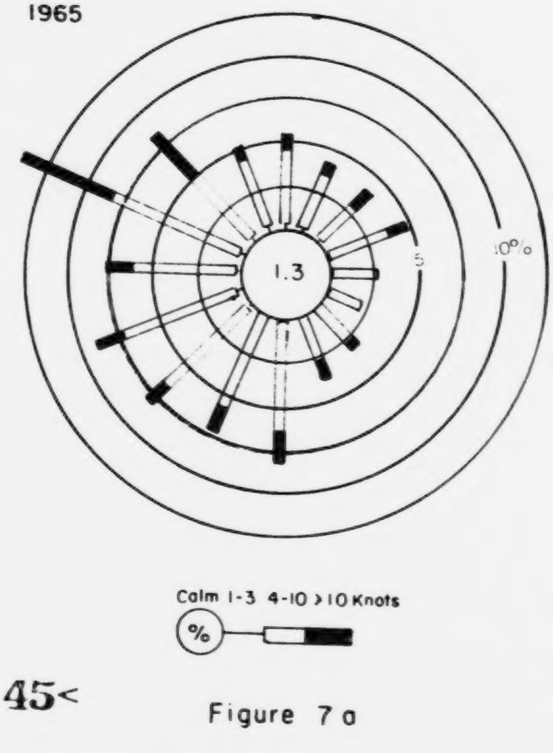


Figure 7a

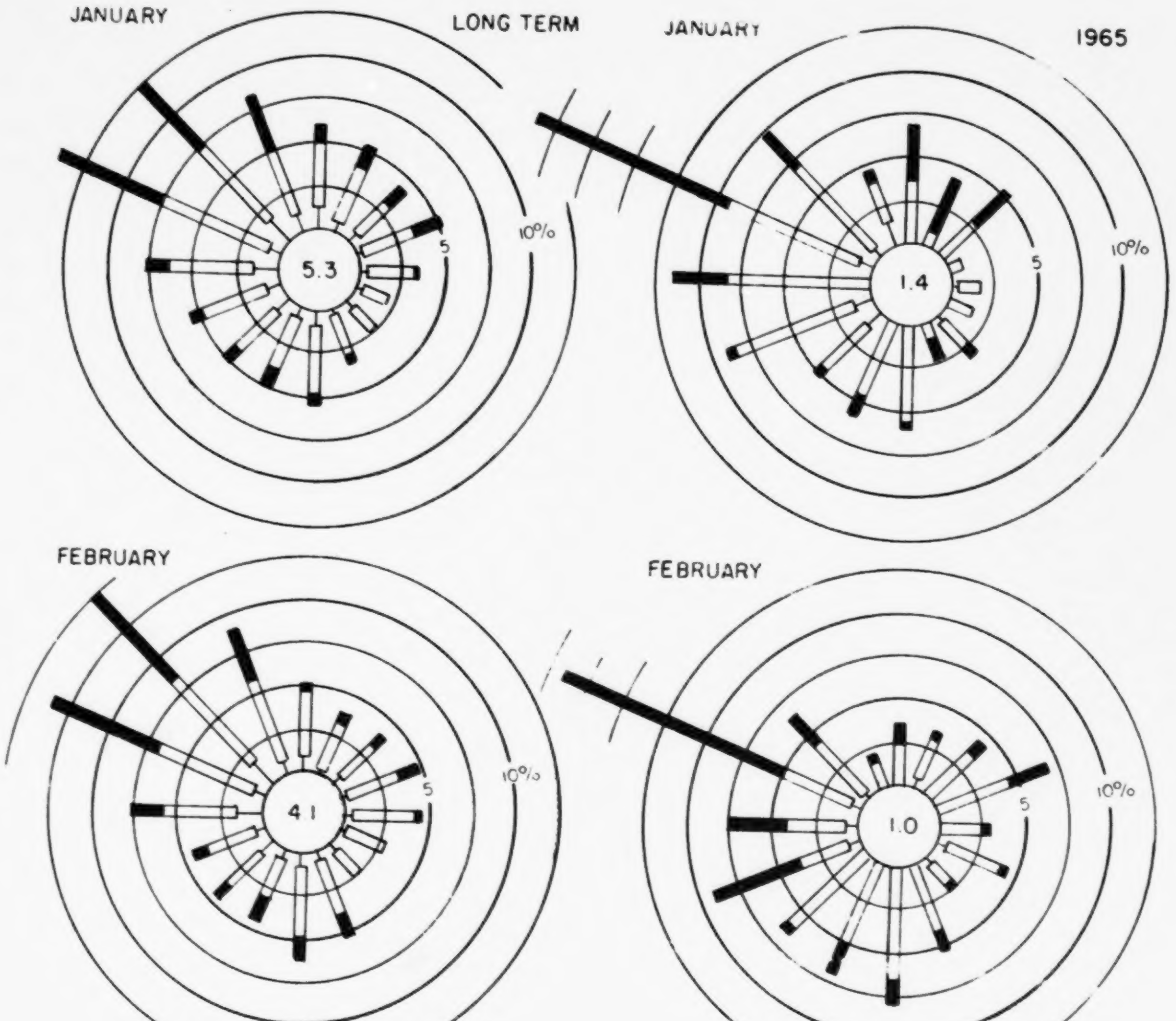
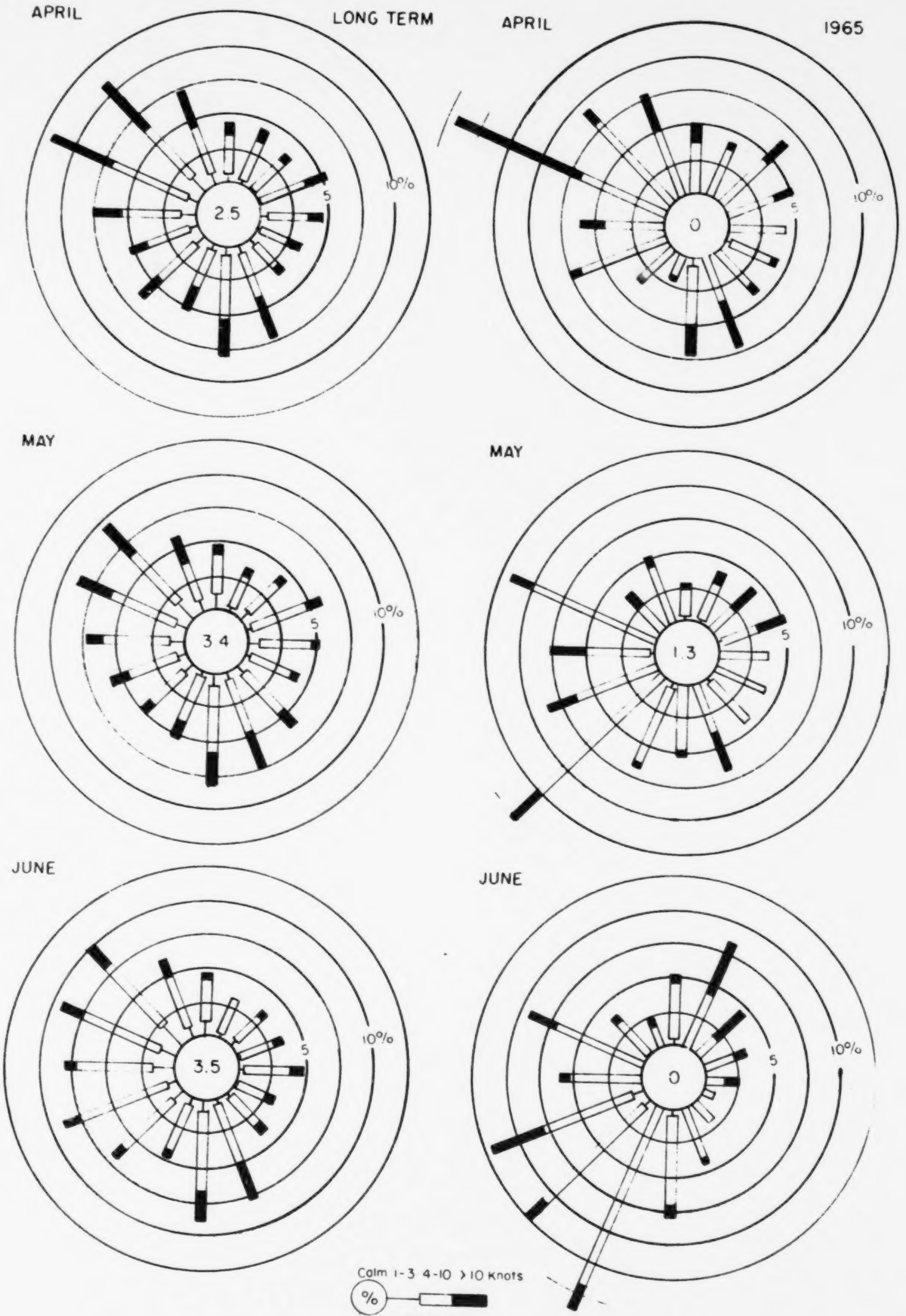

JANUARY
LONG TERM
5.3
5
10%
JANUARY
1965
1.4
5
10%
FEBRUARY
4.1
5
10%
FEBRUARY
1.0
5
10%
MARCH
3.2
5
10%
MARCH
0.5
5
10%
Calm 1-3 4-10 >10 Knots
%

Figure 7 b



APRIL LONG TERM

APRIL 1965

MAY

MAY

JUNE

JUNE

Figure 7c

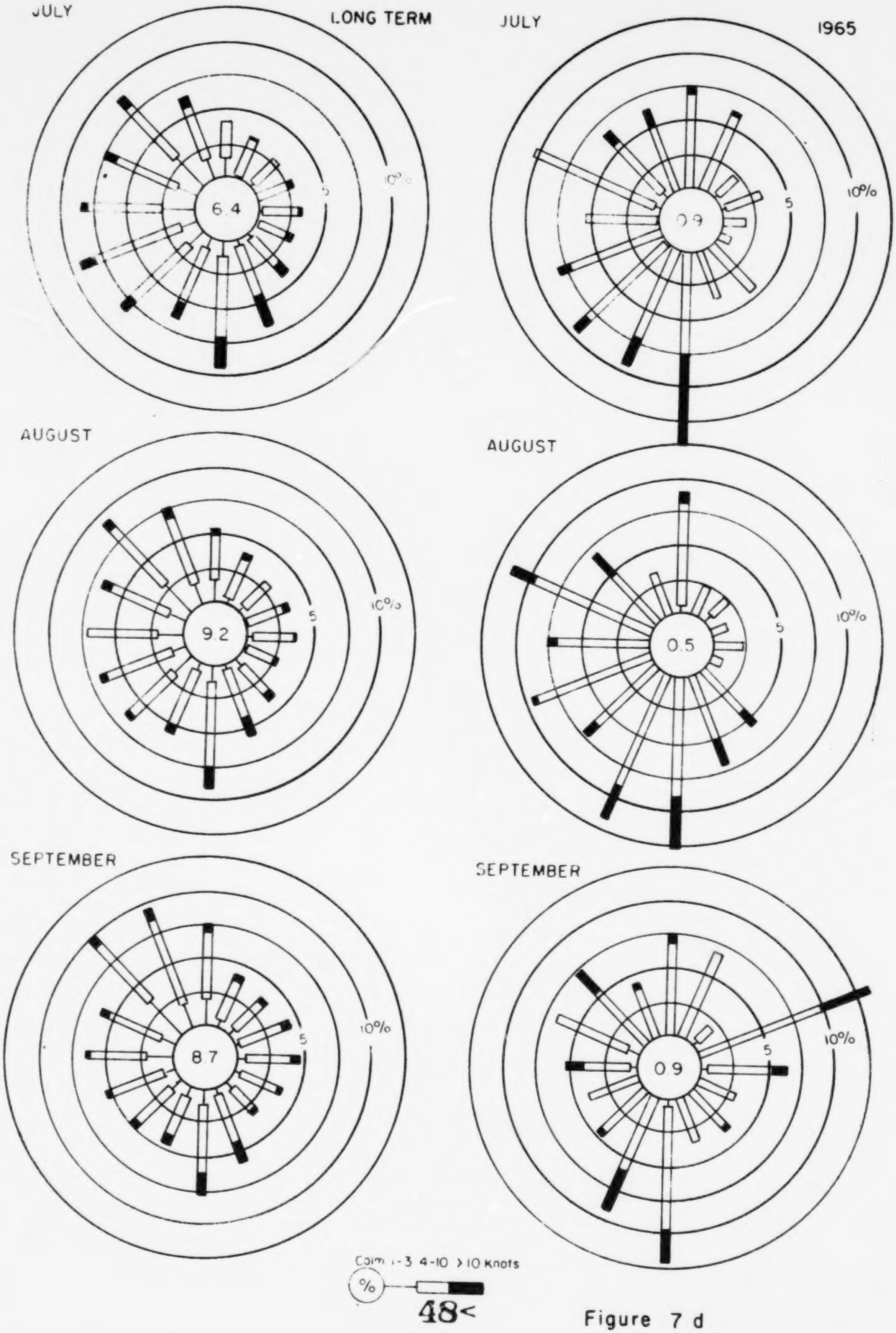

JULY
LONG TERM
6.4
5
10%
JULY
1965
0.9
5
10%
AUGUST
9.2
5
10%
AUGUST
0.5
5
10%
SEPTEMBER
8.7
5
10%
SEPTEMBER
0.9
5
10%
Calm 1-3 4-10 >10 Knots
%

Figure 7 d

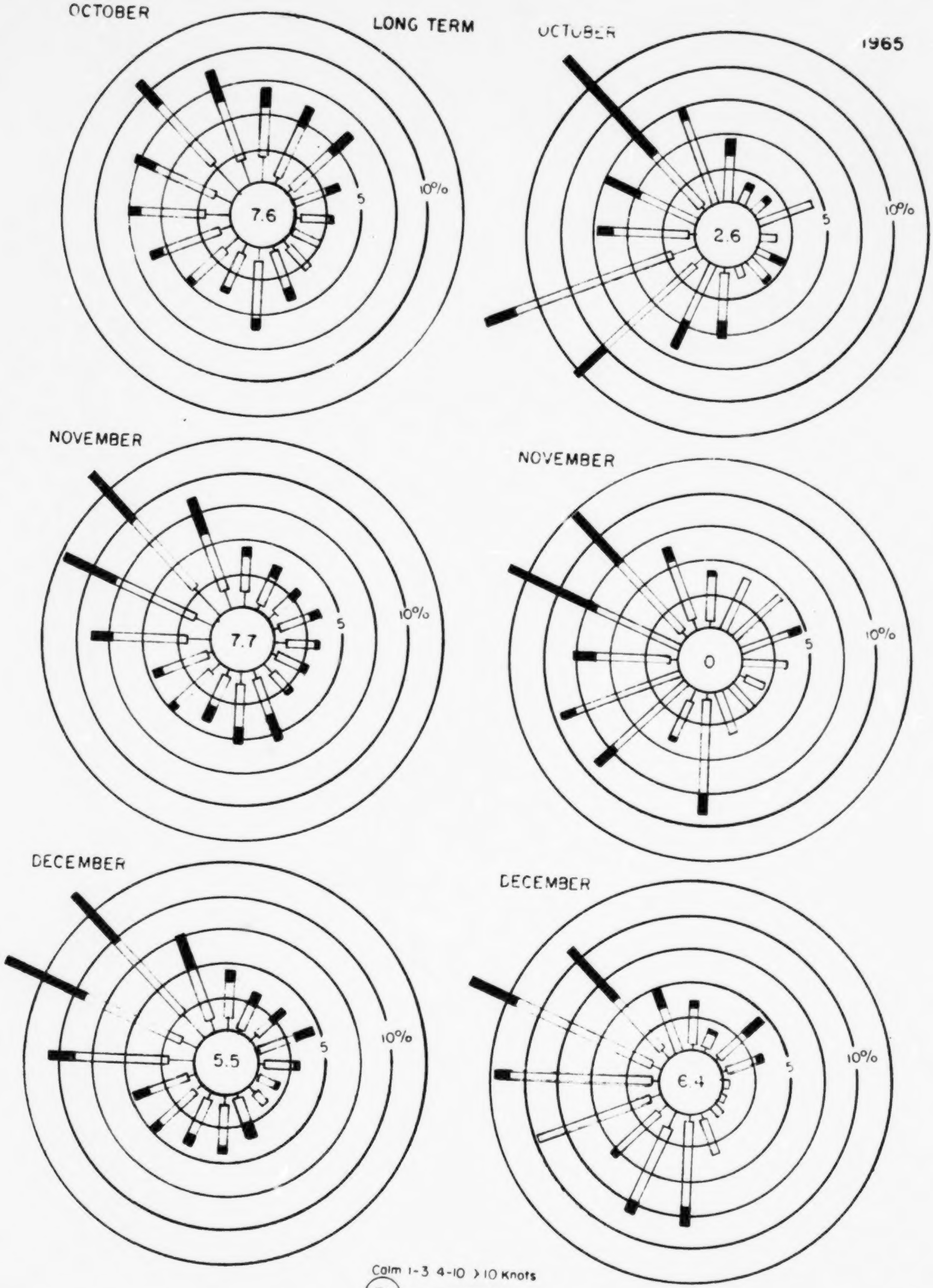

OCTOBER
LONG TERM
OCTOBER
1965
7.6
5
10%
2.6
5
10%
NOVEMBER
NOVEMBER
7.7
5
10%
0
5
10%
DECEMBER
DECEMBER
5.5
5
10%
6.4
5
10%
Calm 1-3 4-10 >10 Knots
%

Figure 7 e

Variation of Wind with Height

All the previous wind roses have represented surface wind observations. Wind speed and direction vary with height and so upper level winds are also of importance to us in considering the movement of pollutants. Only a few observations of winds at limited elevations above the ground are available. The results of observations taken at a site near Delaware City, Delaware, are included in figures 8a through 8e for illustration. The wind roses on these figures show the average annual and the monthly wind conditions in 1965 for the surface and for 250 feet above the surface. Very few differences between the surface and 250 feet are experienced. The only differences that can be found on the diagrams are 1) the larger number of calms experienced at the surface than at 250 feet; 2) the increased wind velocity at 250 feet with a larger number of high velocity winds; and 3) a slight clockwise turning of the wind as one goes up out of the surface friction layer. These differences are all to be anticipated on the basis of meteorological theory as one goes from the surface layer into a layer of less friction and fewer surface influences. The 250 feet between the surface observations and the upper air observations is not sufficient enough for the wind to experience any markedly different characteristics aside from velocity. It might also be pointed out that the observations from both the surface and 250 feet taken at Delaware City agree quite well with the Wilmington, Philadelphia, Allentown observations discussed previously. The Delaware City station is not a Weather Bureau station, but the instruments are operated with care and so provide an excellent series of observations.

Variation of Wind with Time of Day

One final series of observations of wind in the Delaware Valley area is included to show the variation of the wind during different times of the day. These observations from Dover Air Force Base and McGuire Air Force Base, located at the southern and northeastern border of the area respectively, are based on averages of a number of years of record and not on the 1965 record. Figure 9a shows average wind roses for all hours for all months of the year for both of these stations. These roses are quite similar to the averages found earlier for 1965 at representative stations in the Delaware Valley area and on the basis of the long-term picture at Wilmington. One must conclude that both Dover and McGuire observations are also representative of the wind in the Delaware Valley area. Wind observations at Dover taken at 0000-0200, 0600-0800, 1200-1400, and 1800-2000 hours during the day for the months of January, April, July, and October are given in figures 9a through 9e. Roses for similar months and periods for McGuire Air Force Base are included in figures 9f through 9i. The figures show several features that would be anticipated on the basis of theory.

Maximum wind velocity should occur in the afternoon. On these diagrams, the wind observations from 1200 to 1400 hours show fewer calms and higher wind velocities, in general, than at other hours of the day. These differences are apparent in every month of the year.

In January, there is very little difference in the wind direction frequencies during different times of the day. This again is as expected because the winds are generally stronger in January than they are in the summer period of the year. Stronger winds will be less influenced by diurnal heating than will light winds, and therefore they should change less diurnally than light winds. In April a slight shift in the wind from nighttime to daytime occurs both at Dover and McGuire. The midnight and early morning observations at Dover show a predominance of winds from the south through west to north. While the west and northwest directions are also favored at the noontime observations, a large number of winds from east to southeast are also present. In late afternoon, shown by the 1800-2000 hour observations, prevailing directions seem to be east through south. This shift is even more apparent in the McGuire observations which show a strong west or northwest tendency at noontime and a strong south tendency in the late afternoon. Thus there seems to be a counterclockwise shifting of the wind during the period from noontime to sunset and a clockwise shifting from sunset to sunrise.

This type of shift is also found in the July observations at both Dover and McGuire. Winds are generally from south to southwest at midnight and early morning at Dover, shifting to southwest to west by noontime, and then counterclockwise toward the south in the late afternoon. It must be pointed out that at Dover southeasterly directions are also favored at noontime, but there are very few winds from the south. The south direction is re-emphasized again in the sunset observations. The shift at McGuire is more obvious. Southwest winds occur at midnight, southwest to northwest winds develop at noontime, and southerly winds prevail at sunset. Thus from noon to sunset there is a counterclockwise shift in the wind and from sunset to sunrise a clockwise shift in the wind.

The October observations show this diurnal shift even more clearly since at both Dover and McGuire north winds are favored in the early morning hours, and south winds are favored in the evening periods. There is again a counterclockwise wind shift during the daylight hours and a clockwise wind shift during the nighttime hours.

During the daytime, one would expect lower pressure to develop in the vicinity of any large, heated surface. Lower pressures are associated with a counterclockwise wind flow or a cyclonic curvature to the wind. Thus, with heating during the day, we would expect to find a counterclockwise shift of the wind. This is experienced at both Dover and McGuire. With the removal of heating during the nighttime, the winds would shift back in a clockwise direction. Thus the pattern of change found at Dover and McGuire might be anticipated on the basis of daily changes in air temperature and radiation.

Occurrence of Periods of Light Winds

In his study of air pollution in Philadelphia, Davis (1960) analyzed the wind record from July 1949 to June 1959 taken at the Philadelphia International Airport Weather Bureau station. Because of the importance of wind speed on air pollution, Davis provided a good summary of wind conditions in the immediate Philadelphia area.

AVERAGE ANNUAL WIND ROSES, DELAWARE CITY, DELAWARE, 1965, AT THE SURFACE AND AT 250 FT.

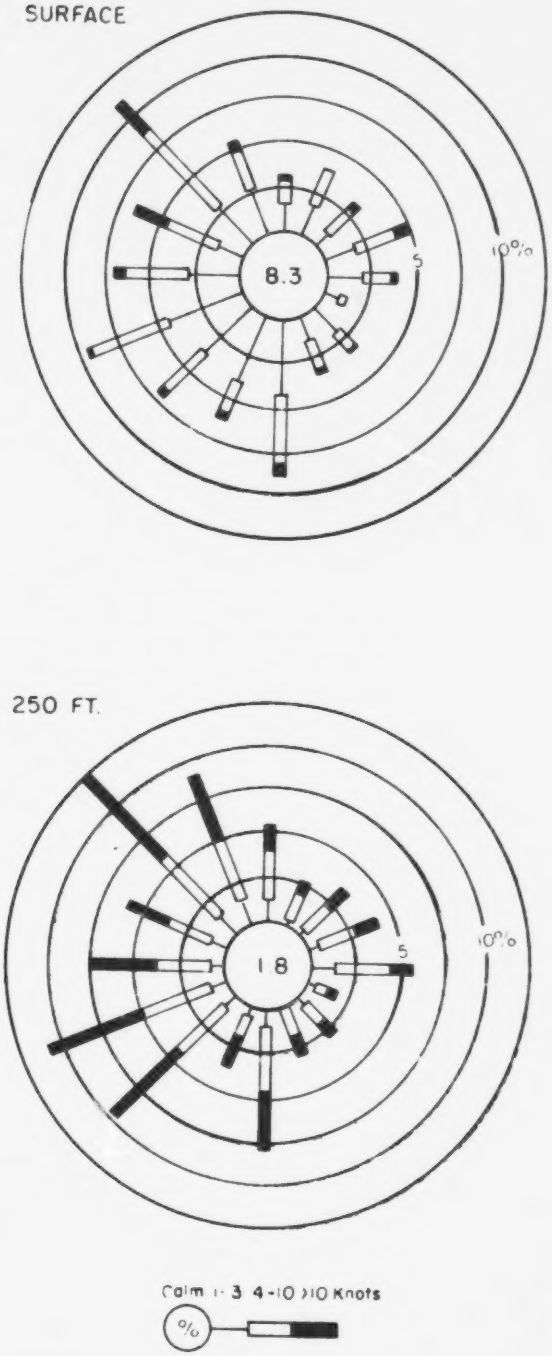


Figure 8 a

AVERAGE MONTHLY WIND ROSES, DELAWARE CITY, DELAWARE, 1965, AT THE SURFACE AND AT 250 FT.

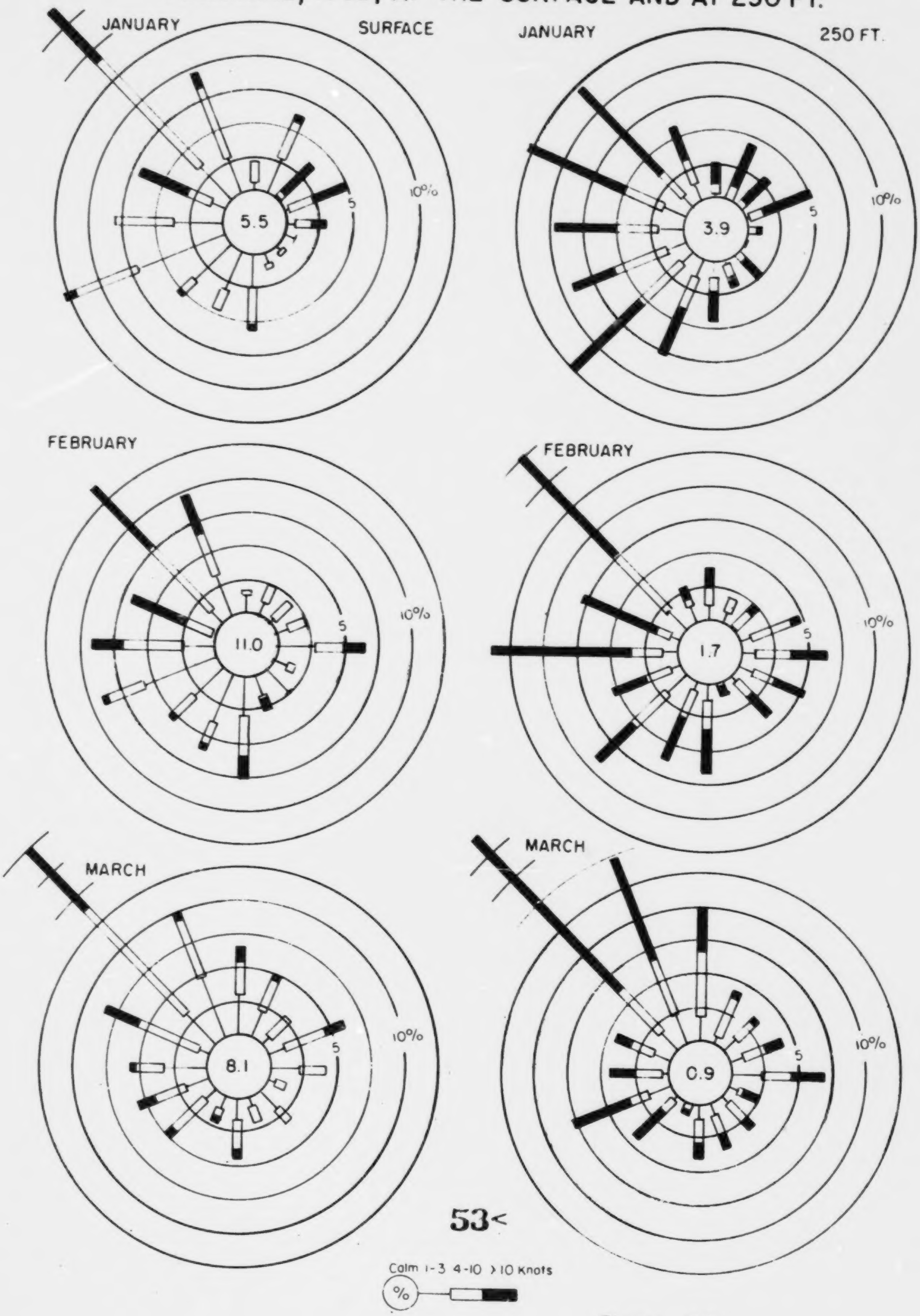


Figure 8 b

AVERAGE MONTHLY WIND ROSES, DELAWARE CITY, DELAWARE, 1965, AT THE SURFACE AND AT 250 FT.

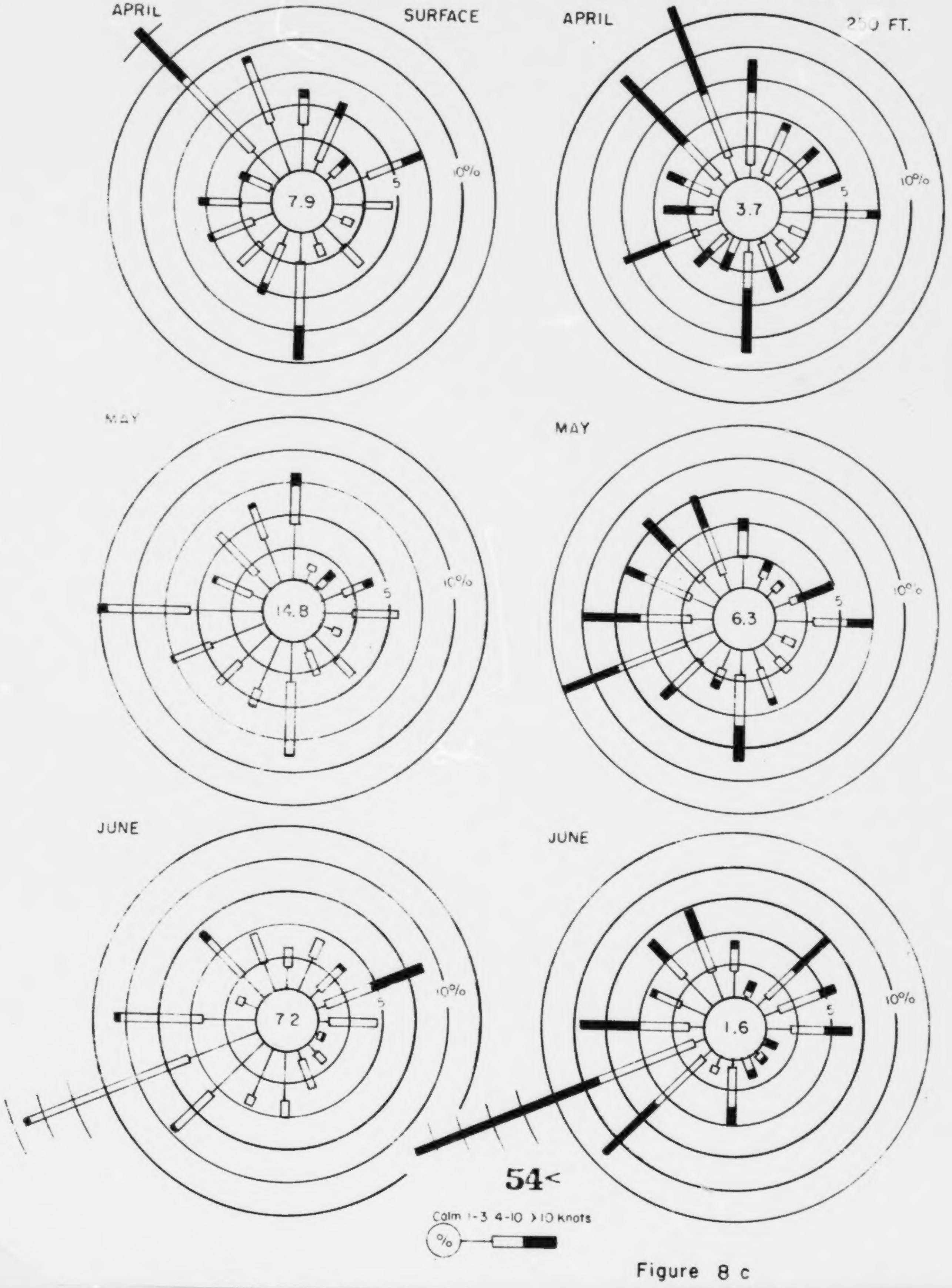


Figure 8 c

AVERAGE MONTHLY WIND ROSES, DELAWARE CITY, DELAWARE, 1965, AT THE SURFACE AND AT 250 FT.

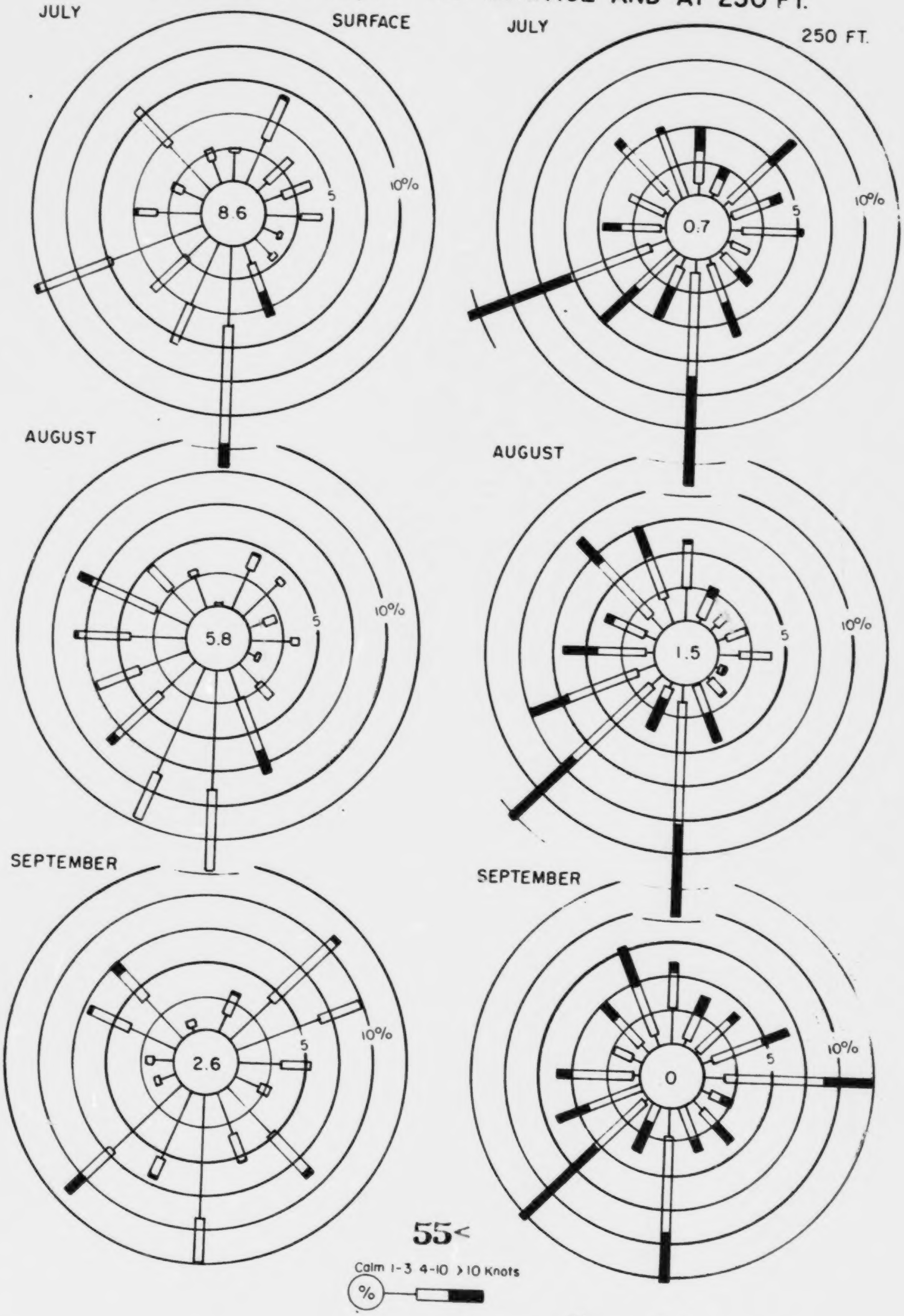


Figure 8 d

AVERAGE MONTHLY WIND ROSES, DELAWARE CITY, DELAWARE, 1965, AT THE SURFACE AND AT 250 FT.

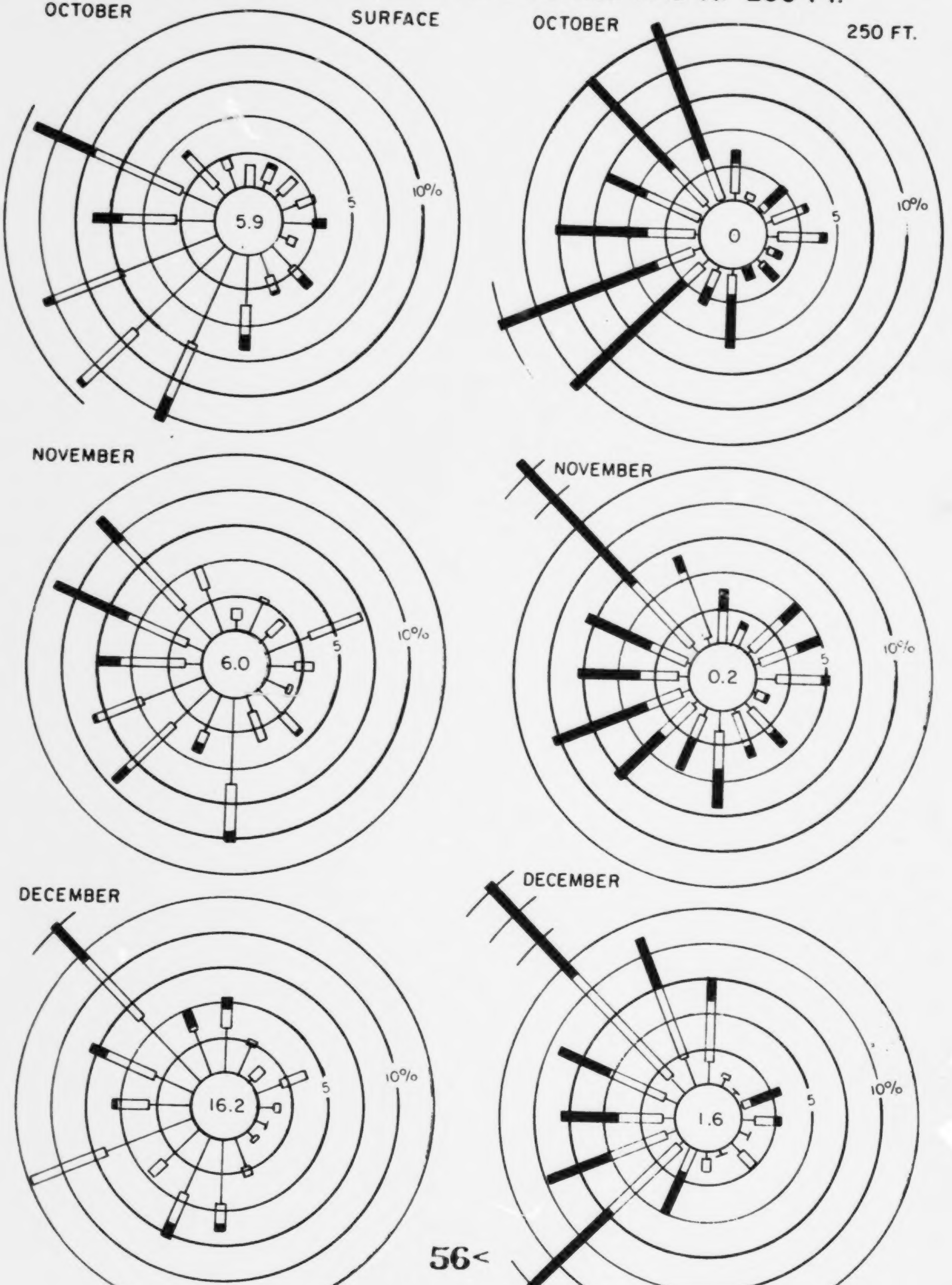
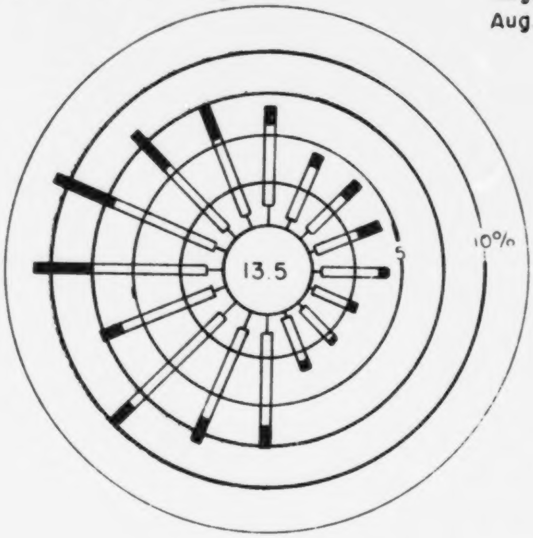


Figure 8 e

AVERAGE ANNUAL SURFACE WIND ROSES
McGUIRE AND DOVER A.F.B.

McGUIRE A.F.B.
ALL MONTHS - ALL HOURS

Aug.'42 - Mar.'46
Aug.'48 - Dec.'64



DOVER A.F.B.
ALL MONTHS - ALL HOURS

Dec.'42 - Sept.'46
July - Sept.'49
Sept.'50 - Mar.'65

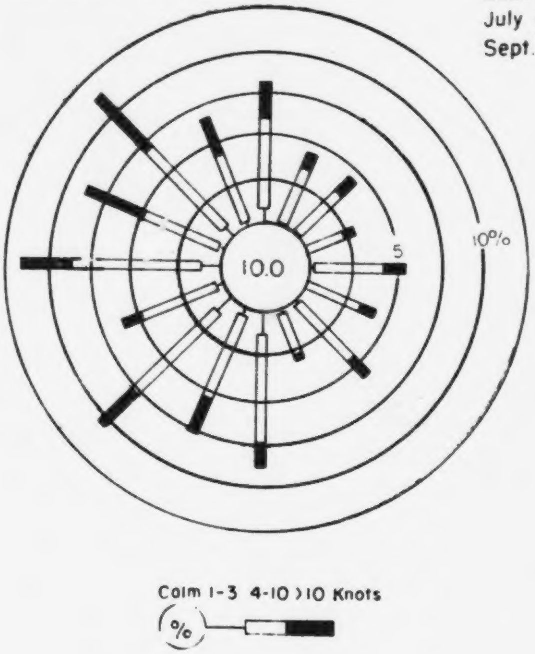
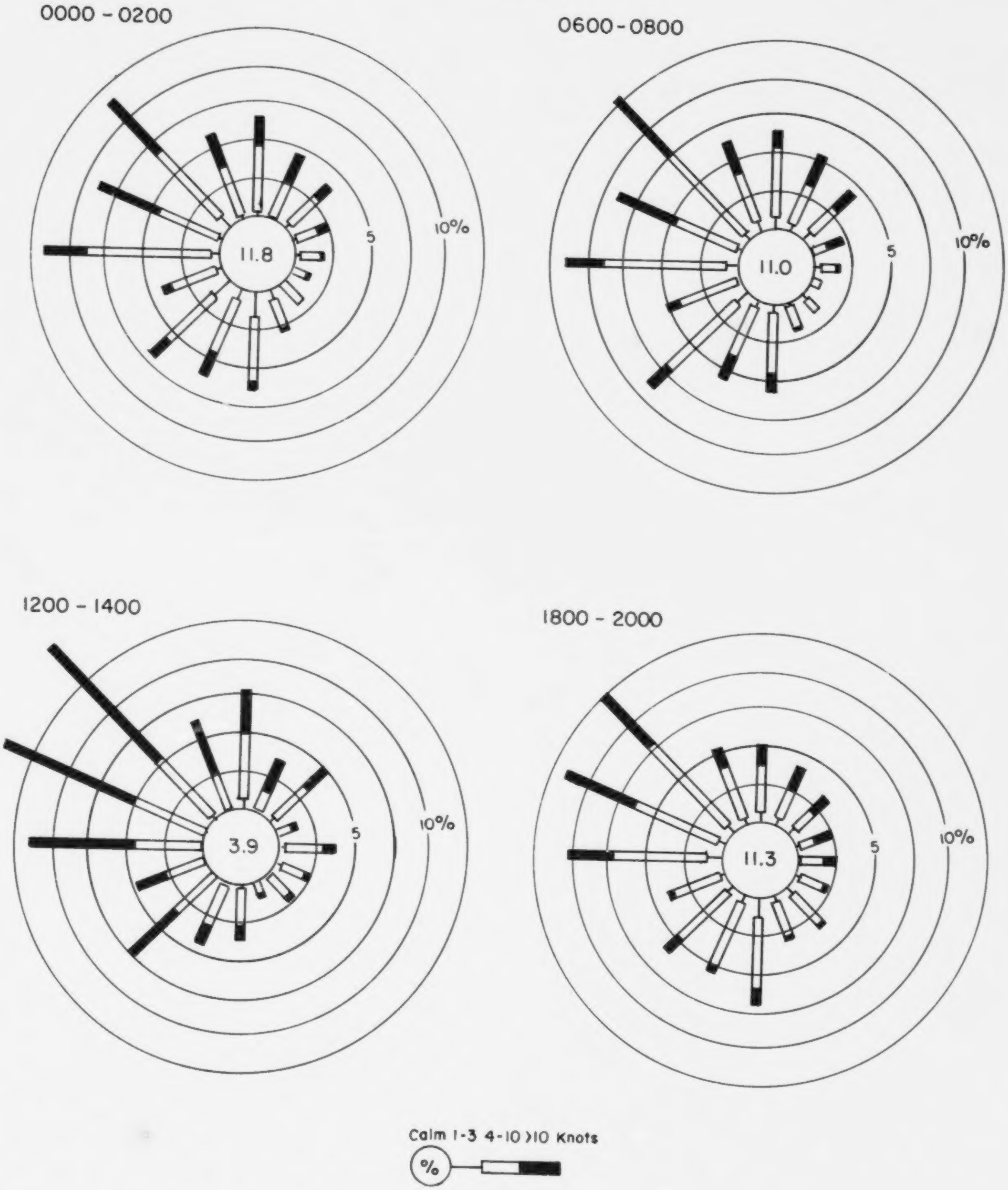


Figure 9a

AVERAGE MONTHLY WIND ROSES, DOVER A.F.B. FOR SELECTED TWO-HOUR PERIODS

JANUARY


0000 - 0200

0600-0800

1200 - 1400

1800 - 2000

Figure 9b

AVERAGE MONTHLY WIND ROSES, DOVER A.F.B.
FOR SELECTED TWO-HOUR PERIODS

APRIL

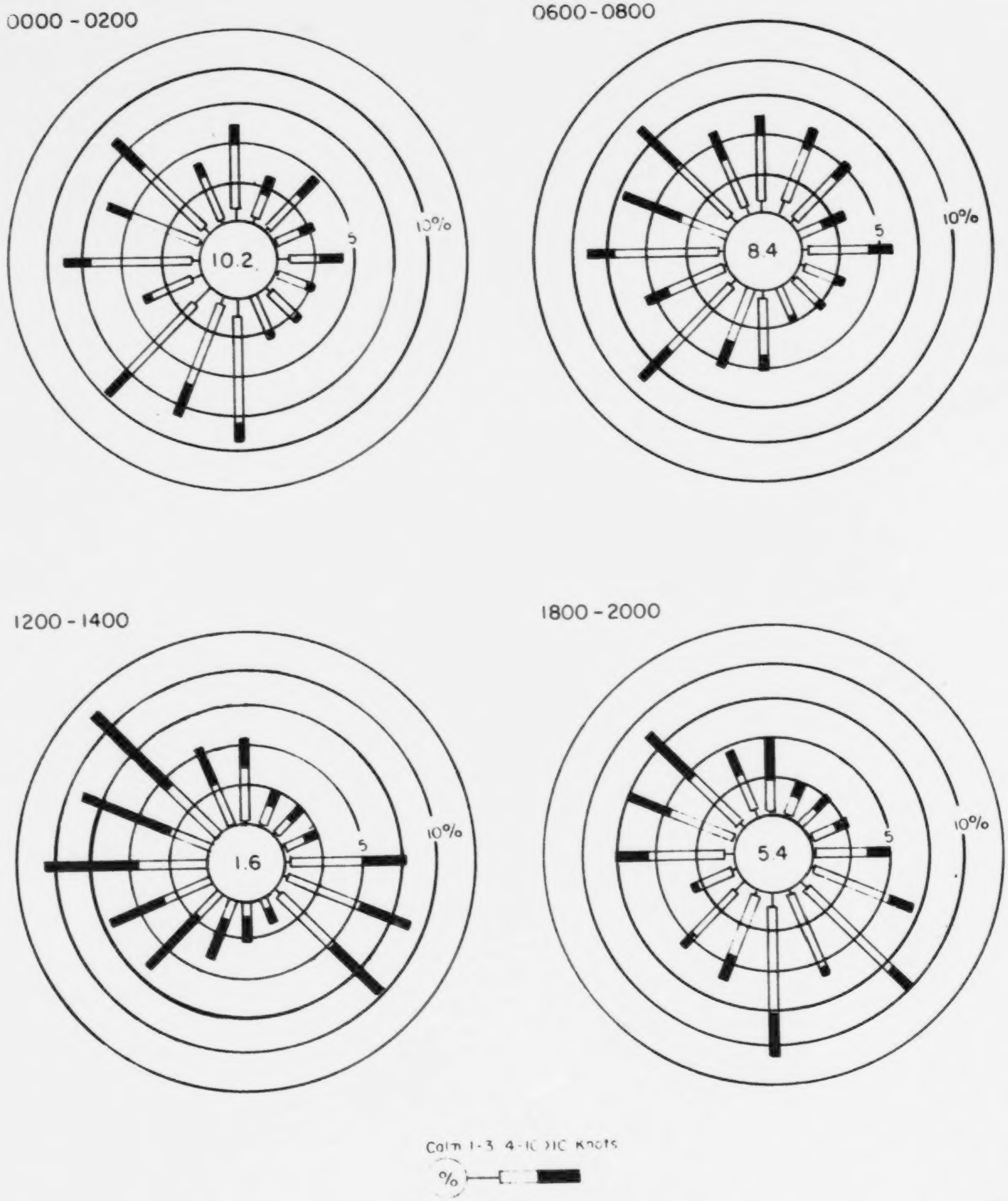


Figure 9c

AVERAGE MONTHLY WIND ROSES, DOVER A.F.B. FOR SELECTED TWO-HOUR PERIODS

JULY

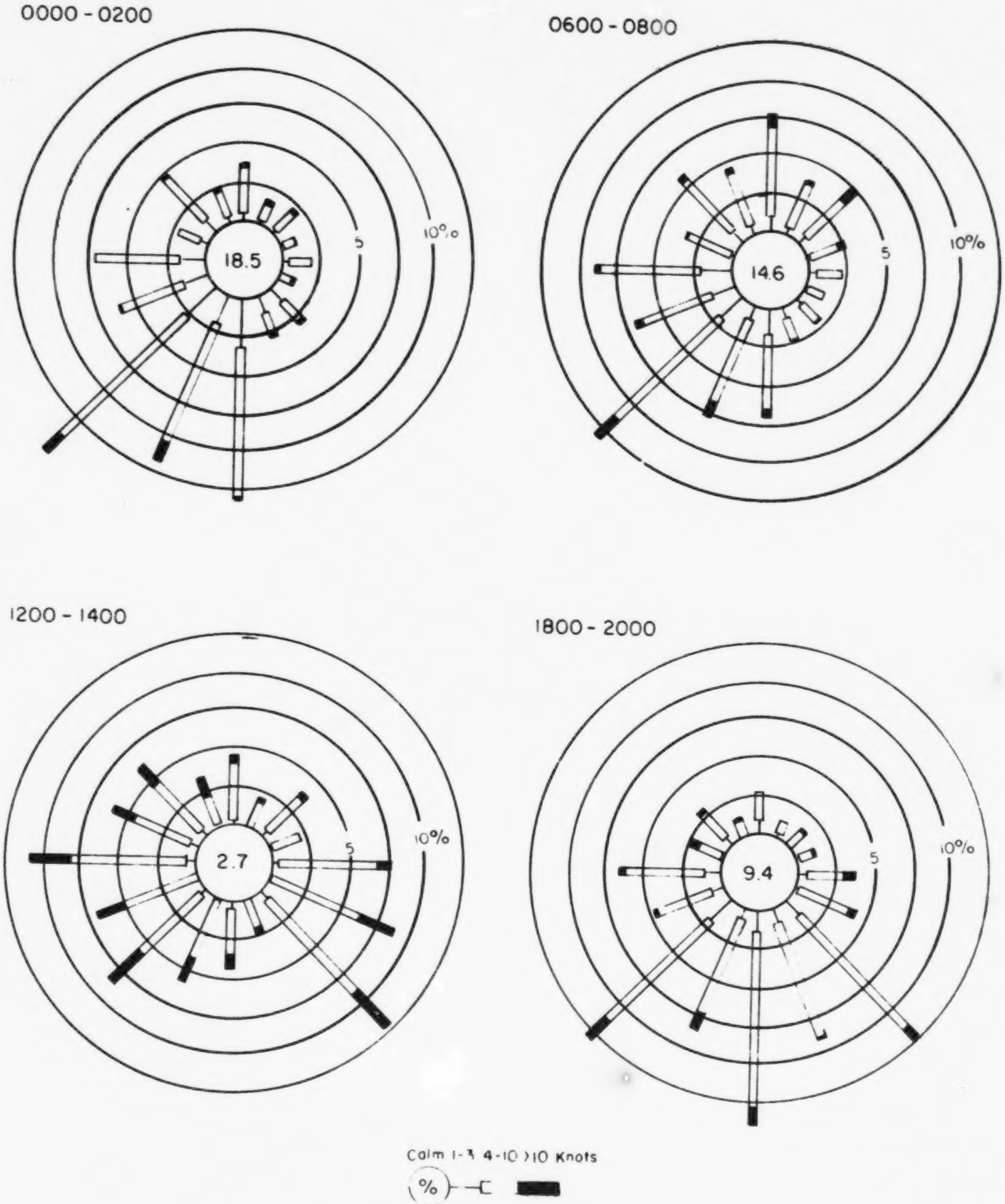
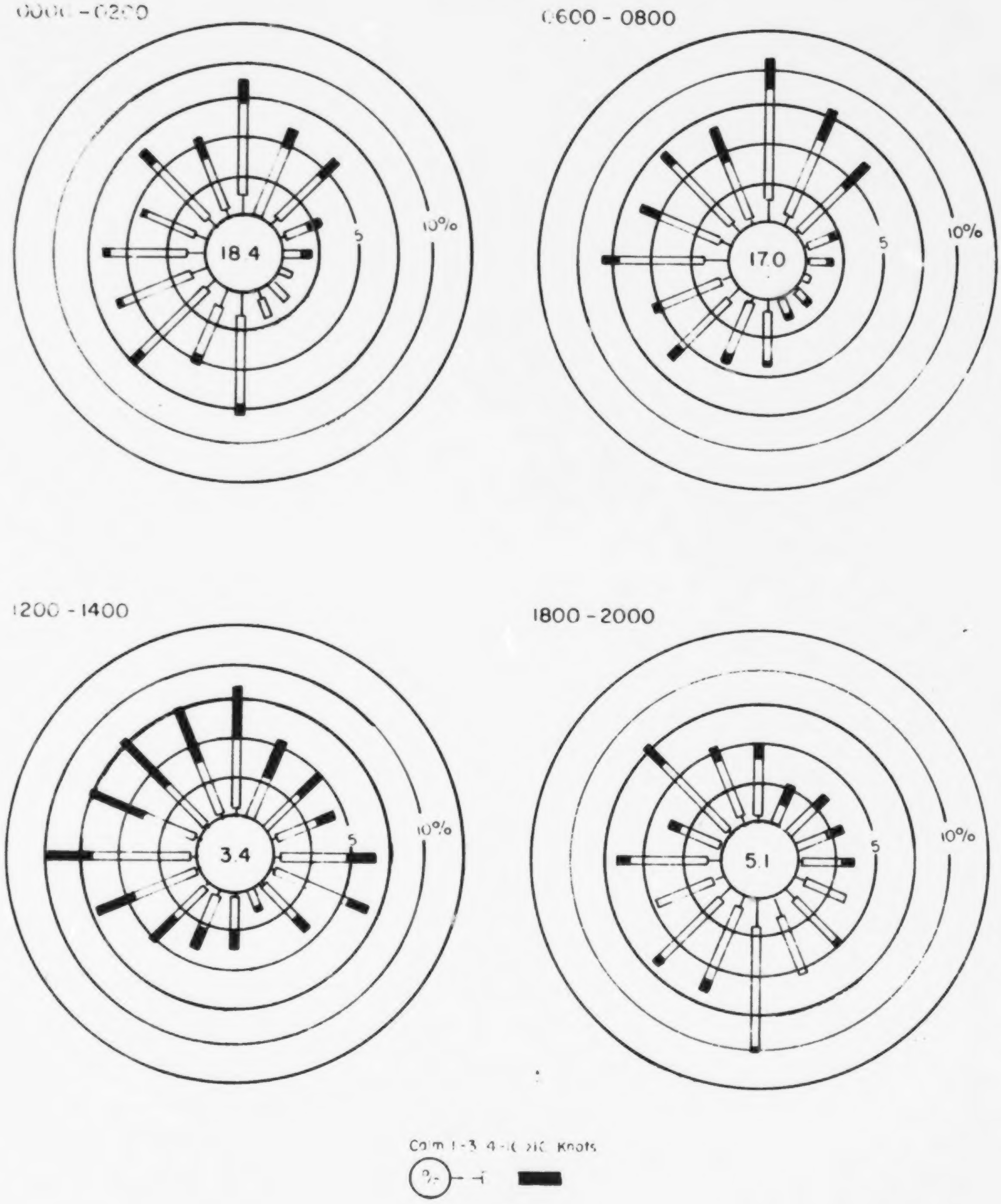


Figure 9d

AVERAGE MONTHLY WIND ROSES, DOVER A.F.B. FOR SELECTED TWO-HOUR PERIODS

OCTOBER



0000 - 0200

0600 - 0800

1200 - 1400

1800 - 2000

Figure 9e

AVERAGE MONTHLY WIND ROSES, McGUIRE A.F.B. FOR SELECTED TWO-HOUR PERIODS

JANUARY

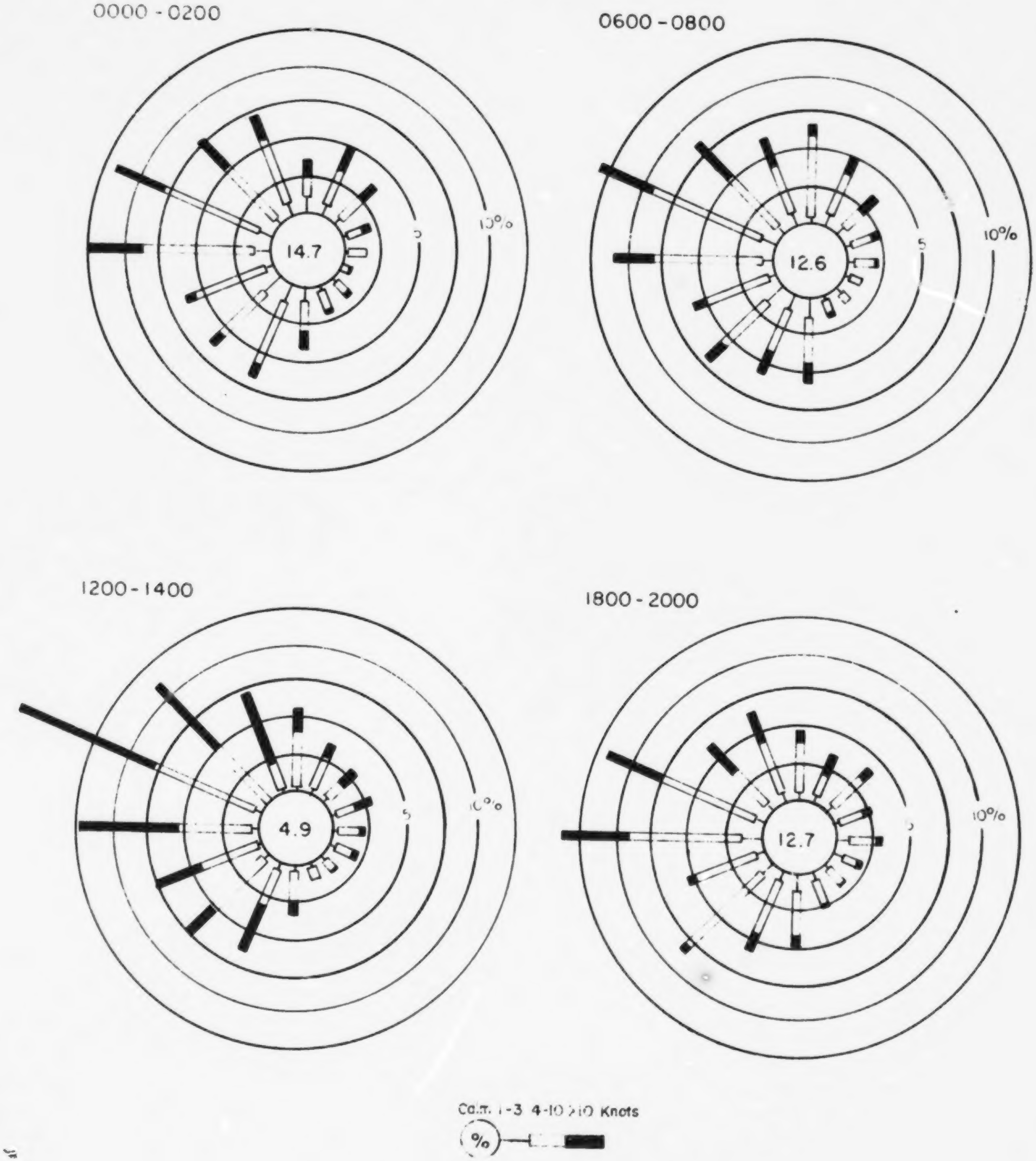
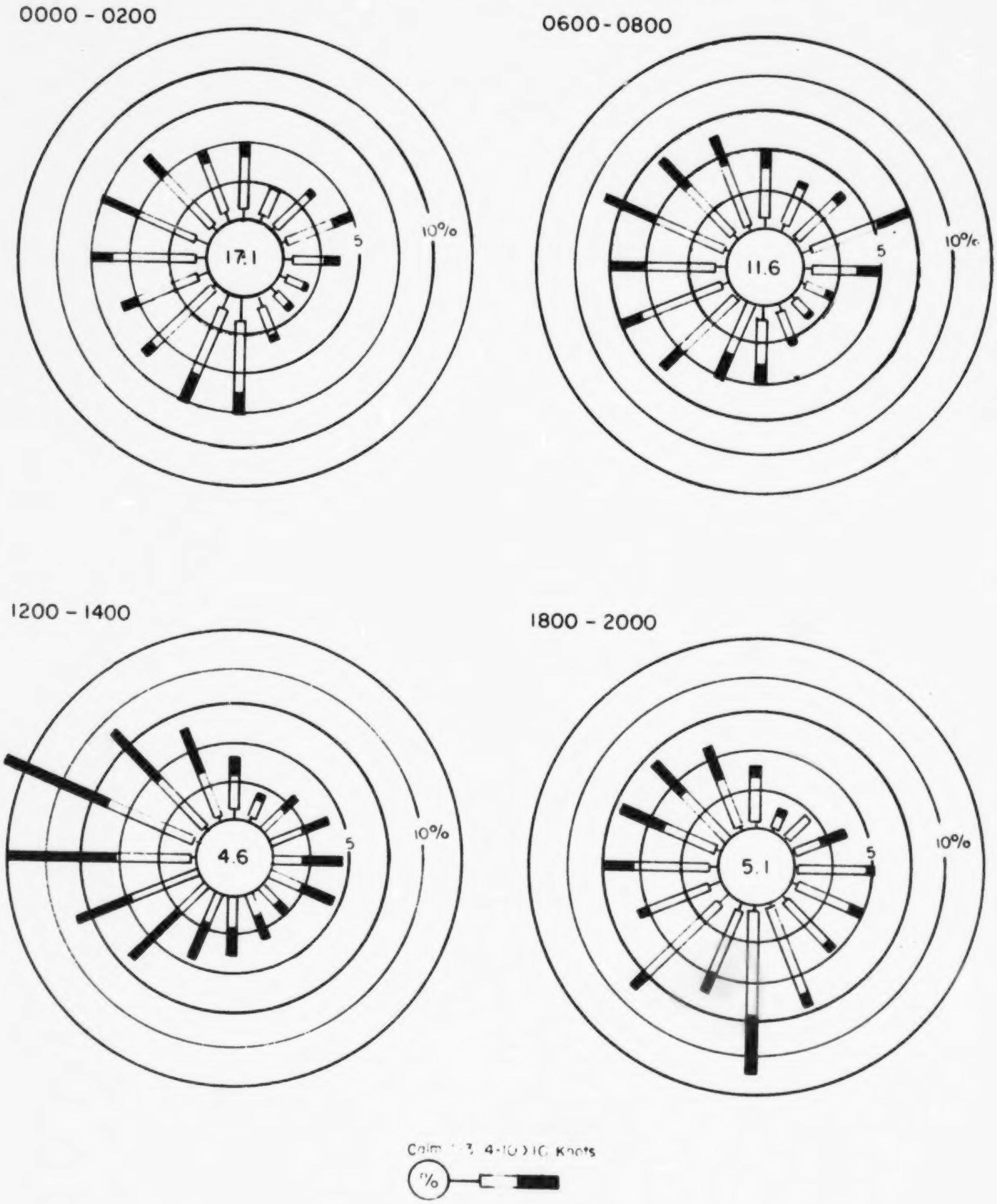


Figure 9f

AVERAGE MONTHLY WIND ROSES, McGUIRE A.F.B. FOR SELECTED TWO-HOUR PERIODS

APRIL



0000 - 0200

0600-0800

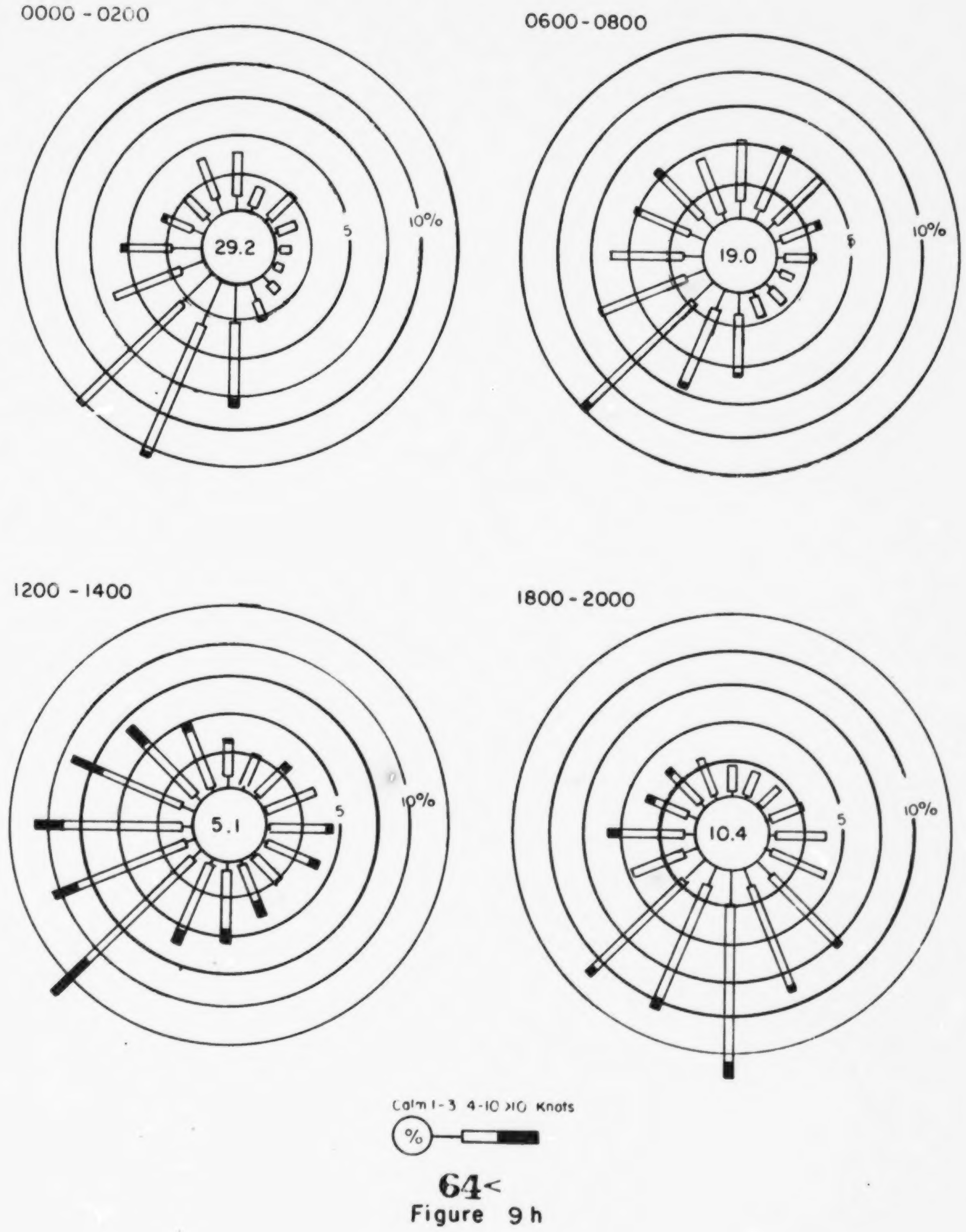
1200 - 1400

1800 - 2000

Figure 9 g

AVERAGE MONTHLY WIND ROSES, McGUIRE A.F.B.
FOR SELECTED TWO-HOUR PERIODS

JULY


0000 - 0200

0600-0800

1200 - 1400

1800 - 2000

Figure 9h

AVERAGE MONTHLY WIND ROSES, McGUIRE A.F.B.
FOR SELECTED TWO-HOUR PERIODS

OCTOBER

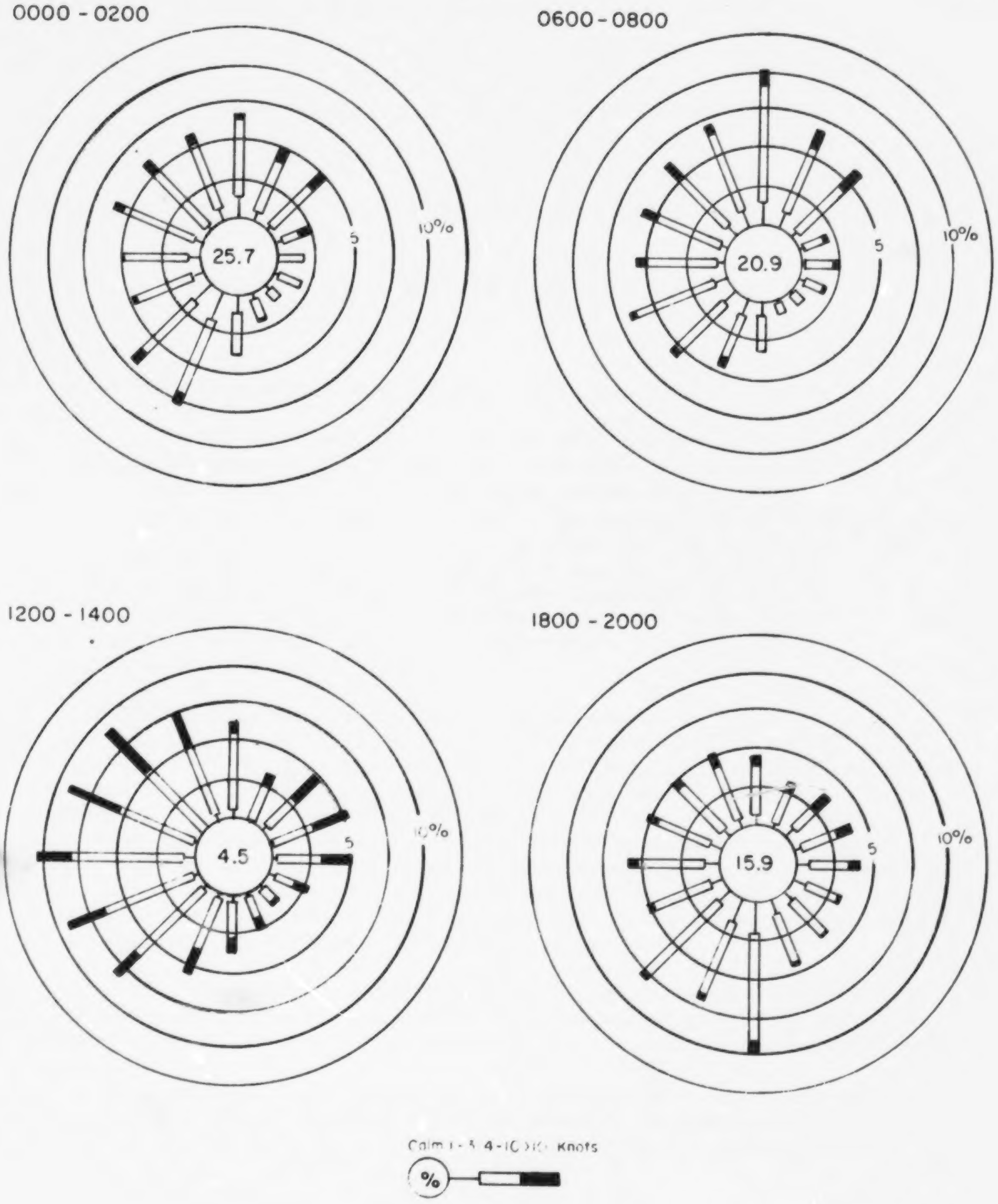


Figure 9 i

Table 2 (adapted from Davis, 1960) gives the mean wind speed by months, based on the ten-year record, and the percentage of time the wind was less than 8 mph each month.

Table 2

Wind Summary, Philadelphia, 1949-1959

	J	F	M	A	M	J	J	A	S	O	N	D
Mean Wind Speed (mph)	10.1	11.0	12.2	11.2	8.9	9.0	7.8	7.2	7.9	8.5	9.5	10.0
% of time wind <8 mph	33	33	24	28	33	40	44	49	46	40	37	34

On the basis of his wind summary, Davis concluded:

> "It is definitely noticeable that the period of lightest winds is summer and fall, particularly late summer and early fall. This coincides with the period of maximum frequency of clear skies at night. The latter condition contributes to low level cooling at night and the formation of inversions. Thus, the large scale weather observations would indicate that poorest diffusion conditions in the Philadelphia area occur in the late summer and early fall, and are associated, in general, with winds from a southwesterly direction." (p. 18)

The wind data were further analyzed to provide information on the number of times there were 12 or more consecutive hours of wind speeds below 4 and 8 mph since it was felt that low wind speeds existing for long periods of time were directly related to periods of higher atmospheric pollution. During the 10 years of record, twenty-five periods with wind speeds less than 4 mph for 12 or more consecutive hours were found, and 454 periods with wind speeds less than 8 mph for 12 or more consecutive hours were found. Only 46 of these latter periods (8 mph or less) lasted for 24 or more consecutive hours, but the distribution of these periods is important because of the influence wind speed plays in transporting and dispersing atmospheric pollution.

Table 3 summarizes the monthly frequencies of periods with low wind speeds and shows that in every case there is a definite late summer or early fall maximum (October, or August to November) for the persistence of light winds.

Thus on the basis of consecutive hours with low wind speeds which, of course, produce low ventilation rates and possibly high atmospheric pollution, the early fall period would have to be considered to be the most hazardous.

Table 3

Monthly Frequencies of Light Winds for 12 or 24 Consecutive Hours
Philadelphia, 1949-1959 (After Davis, 1960)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Wind speed <4 mph 12 consecutive hours or more	1	0	0	0	4	0	0	1	0	6	8	5	25
Wind speed <8 mph 12 consecutive hours or more	44	29	8	11	27	28	38	63	60	50	55	41	454
Wind speed <8 mph 24 consecutive hours or more	5	3	0	1	2	0	3	3	7	10	5	7	46

Wind Flow During Periods of High and Low Pollution

Davis (1960) investigated 24 episodes or periods during which high levels of suspended particulates were recorded on air samplers located at City Hall Annex and 3200 Frankfurt Avenue in Philadelphia during the years 1957-1959. From a description of the general meteorological situation during each of these periods of high pollution, he prepared a general description of weather conditions likely to lead to increasing air pollution conditions. He described these conditions as follows:

> "A continental polar high pressure center moves out of Canada across the Great Lakes, sometimes going slowly across New York State and off the Northeast coast, sometimes down into the Ohio Valley and eastward across the Middle Atlantic area to the Mid-east or Northeast coast. These highs become stationary or very slow moving at the coast, and the Philadelphia area is influenced by very light winds for several days. Most of that period is generally spent on the west side of the high pressure center so the air flow is predominantly from a direction between southeast and southwest, with southwest heavily favored. Wind speeds during these problem periods were predominantly less than 8 mph, and during 15 of those periods such speeds were recorded continuously for 14 hours or longer. It is noticeable that high pollution levels were recorded with somewhat higher wind speeds in the spring season." (pp. 38-39)

A study of 13 periods of very low atmospheric pollution during the same three-year period again showed a fairly consistent pattern. Very low atmospheric pollution was associated with a weather pattern resulting in high, gusty winds and a fresh continental polar air mass over the Philadelphia area. This was usually associated with a low pressure area centered just east or northeast of Philadelphia with a high to the west. Winds would therefore be northerly or northwesterly and speeds would often be 20 to 30 mph.

Davis tabulated the wind directions associated with periods of high atmospheric pollution in Philadelphia to see if any significant directional pattern occurred. Using an 8-point compass (north and north-northeast grouped under north, etc.), his results are included in figure 10. This is a composite wind rose covering all periods of high air pollution regardless of season of the year. The rose shows a very high percentage of winds from the southwest and only a moderate number of calm conditions. The fact that nearly 40 percent of the winds were from the southwest, however, probably reflects two situations: 1) low wind velocities and high pollution were associated with stagnant high pressure areas located just east of Philadelphia resulting in southwest winds; 2) significant concentrations of smoke sources in the southwest would result in higher pollution as low winds blew the pollution conditions into the city itself.

As a result of current studies of pollution episodes in 1965 (to be described in chapter V), we have been able to identify a number of periods with appreciably above normal and appreciably below normal air pollution in the vicinity of Philadelphia. Wind roses have been prepared using data from Philadelphia International Airport, Wilmington-Newcastle AP, and Phoenixville for just those days of much above and much below normal soiling index (figure 11a), much above and below normal concentrations of suspended particulates (figure 11b), and much above and below normal concentrations of nitrogen dioxide (figure 11c). While there is some discrepancy in the actual days used in the preparation of these figures, there are enough similar days to lead one to suspect that all three wind roses during high pollution periods would be quite similar as would the roses for low pollution periods. This is certainly borne out by the wind roses in figures 11a to 11c.

At times of above normal soiling index, suspended particulate concentration, and nitrogen dioxide concentration, winds were generally light (calms 13.8, 26.1, and 22.4 percent of time respectively) and from the southwest (total percent of wind from south to west quadrant 49, 47, and 36 percent respectively). In two of the three cases, the next most prevailing direction was directly opposite or northeast. These directions and speeds agree with the idea of light, variable winds, generally from the southwest on the western side of a high pressure center at the time of lowered air quality.

The three wind roses prepared for times of below normal soiling index, suspended particulate concentration, and nitrogen dioxide concentration show, on the other hand, strong wind velocities and wind generally from the northwest sector. These conditions are undoubtedly associated with fresh outbreaks of cold, continental polar air from Canada which are known to bring reduced pollution conditions and clear, crisp air. Calm conditions existed 1.7, 7.2, and 6.3 percent of the time with these better air quality conditions, and winds were strong and from the west to north quadrant 73, 56, and 60 percent of the time.

Weather and circulation conditions seem more clear-cut and definitive at times of improved air quality than at times of lowered air quality. This is to be expected for there are undoubtedly a greater variety of environmental conditions that can lead to high pollution levels than to low pollution levels. Eliminating holiday periods and weekends, the only factors leading to improved air quality must be meteorologic and related to outbreaks of strong, unstable winds. However, under light wind conditions which could exist with a variety of meteorologic conditions, or under environmental conditions which might be influenced by local heavy releases of pollutants also under a variety of meteorologic conditions, air quality can be poor. Thus, quite similar meteorologic conditions do not always occur with lowered air quality. The wind roses do show, however, the basic meteorologic control exercised by wind speed and the influence of certain general circulation conditions on the concentration or dispersion of pollutants even though conditions are not unique enough to serve satisfactorily as real forecasting aids.

Relationship Between Wind Flow and Inversions

From 1954 to 1956, temperature profiles in the lowest air layers were obtained from a radiosonde station located in Springfield, Delaware County, at the site of a U. S. Army Anti-Aircraft Battalion. These observations have been studied to determine the frequency of significant (2°F or greater per 600 ft) or marked (4°F or greater per 600 ft) temperature inversions (see chapter IV).

Davis (1960) prepared wind roses for all inversions and for marked inversions using data from October 1954-March 1956. The wind roses are given in figures 12 and 13 drawn to only 8 cardinal compass points. (The actual data are included later in tables 7 and 8.) Four categories of wind velocity have been considered: calm, 1-3, 4-8, and >8 miles per hour.

For all inversion conditions, the wind was from the southwest 17.4 percent of the time, from the west 16.4 percent, and from the northwest 17.4 percent of the time. The wind came from these three directions for a total of 51.2 percent of the time. Under conditions of only marked inversions, the wind came from the southwest 17.2 percent of the time, from the west 19.8 percent, and from the northwest 15.5 percent, for a total of 52.5 percent of the time from these three directions. While there are small differences between these wind roses during inversion periods and wind roses based on all hours of observation, these difference would not seem to be significant. The pattern found earlier for all hours of observations, winds generally from the west, ranging from north of west in the winter to south of west in the summer, still seems to prevail during inversion conditions.

One interesting aspect of these wind roses is the relatively low frequency of calms or very light winds. Actually, on both wind roses it can be seen that no calms were found during periods of inversions during the 18 months under investigation. At the same time, the number of occurrences of winds 1-3 miles per hour was much less than the number of higher velocity winds that occurred during inversions. Because of the stable conditions that exist at times of inversions, one might normally expect the occurrence of lighter wind velocities during inversions. This pattern did not seem to occur on the basis of the 1954-1956 Springfield observations. An actual tabulation of the frequency of different velocity winds shows that during periods of significant inversions, winds were 1-3 miles per hour just over 10 percent of the time, while they were between 4-8 miles per hour 47 percent of the time, and 9 miles or over 42 percent of the time. During periods of marked inversions winds were between 1-3 miles per hour just over 11 percent of the time, while they were between 4-8 miles per hour 48 percent of the time, and 9 miles or over almost

PERCENTAGE FREQUENCY OF WIND DIRECTIONS DURING PERIODS OF HIGH POLLUTION 1957-1959 (AFTER DAVIS 1960)

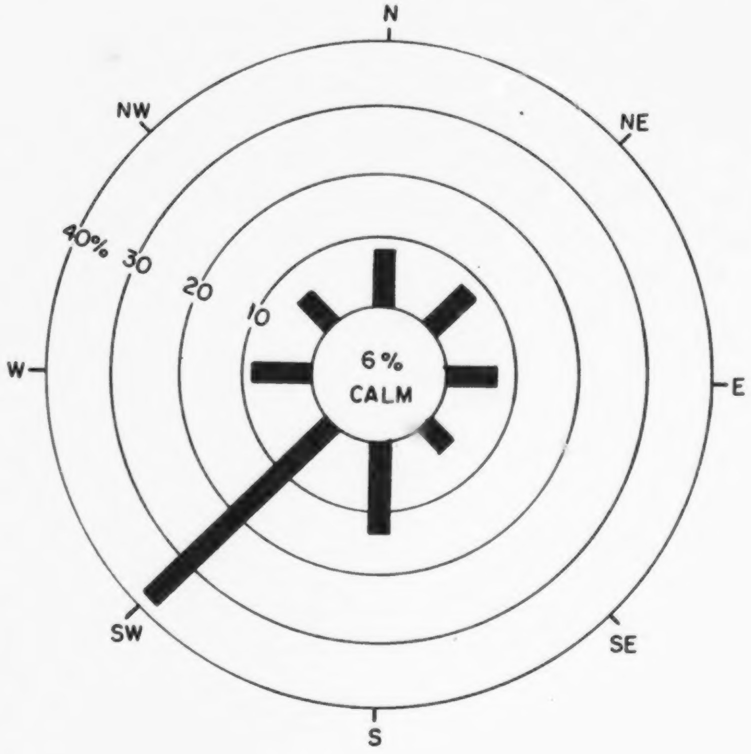
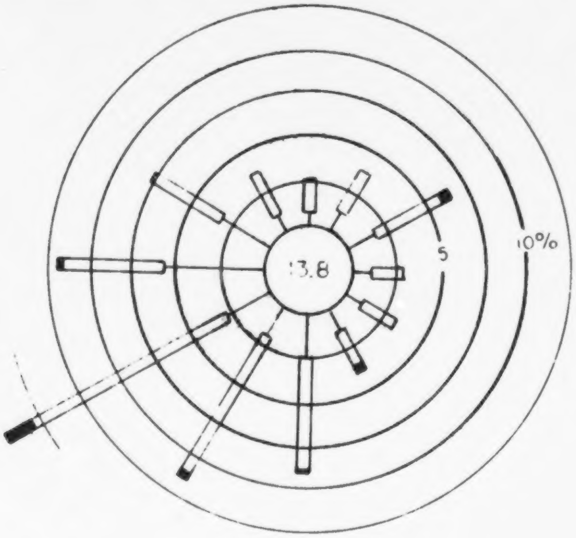


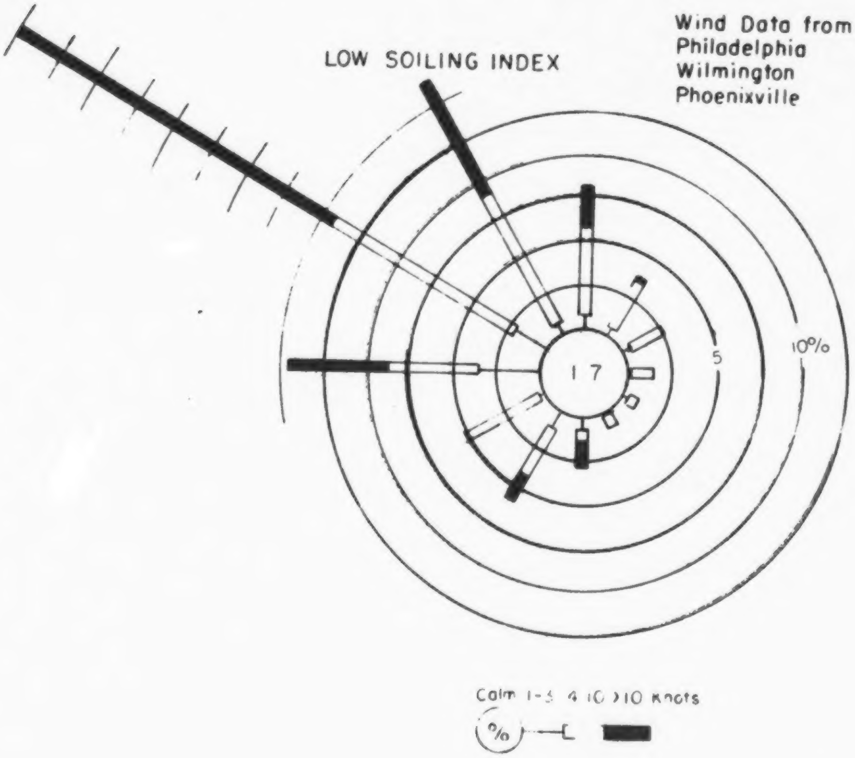
Figure 10

COMPOSITE WIND ROSES, DELAWARE VALLEY AREA, 1965 - DURING PERIODS OF HIGH AND LOW SOILING INDEX

HIGH SOILING INDEX



LOW SOILING INDEX

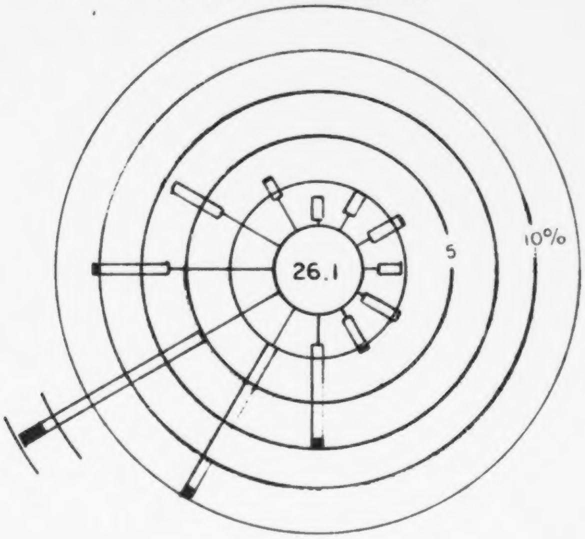


Wind Data from
Philadelphia
Wilmington
Phoenixville

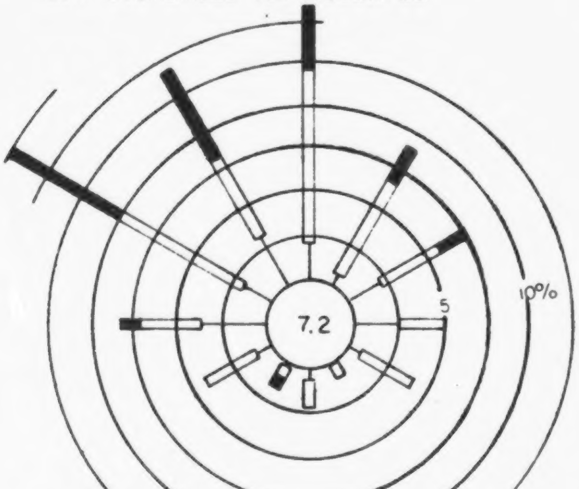
Figure 11a

COMPOSITE WIND ROSES, DELAWARE VALLEY AREA, 1965 - DURING PERIODS OF HIGH AND LOW SUSPENDED PARTICULATE CONCENTRATIONS

HIGH SUSPENDED PARTICULATES



LOW SUSPENDED PARTICULATES



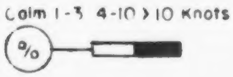
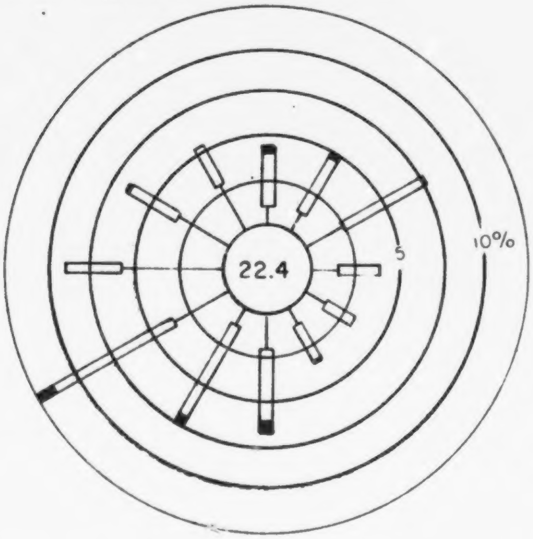


Figure 11b

COMPOSITE WIND ROSES, DELAWARE VALLEY AREA, 1965 - DURING PERIODS OF HIGH AND LOW NO_2 CONCENTRATIONS

HIGH NO_2 CONCENTRATION



LOW NO_2 CONCENTRATION

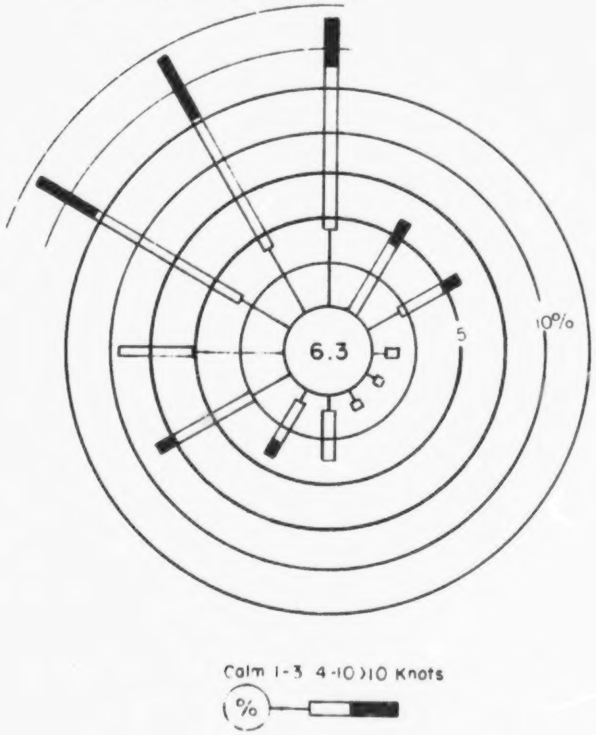
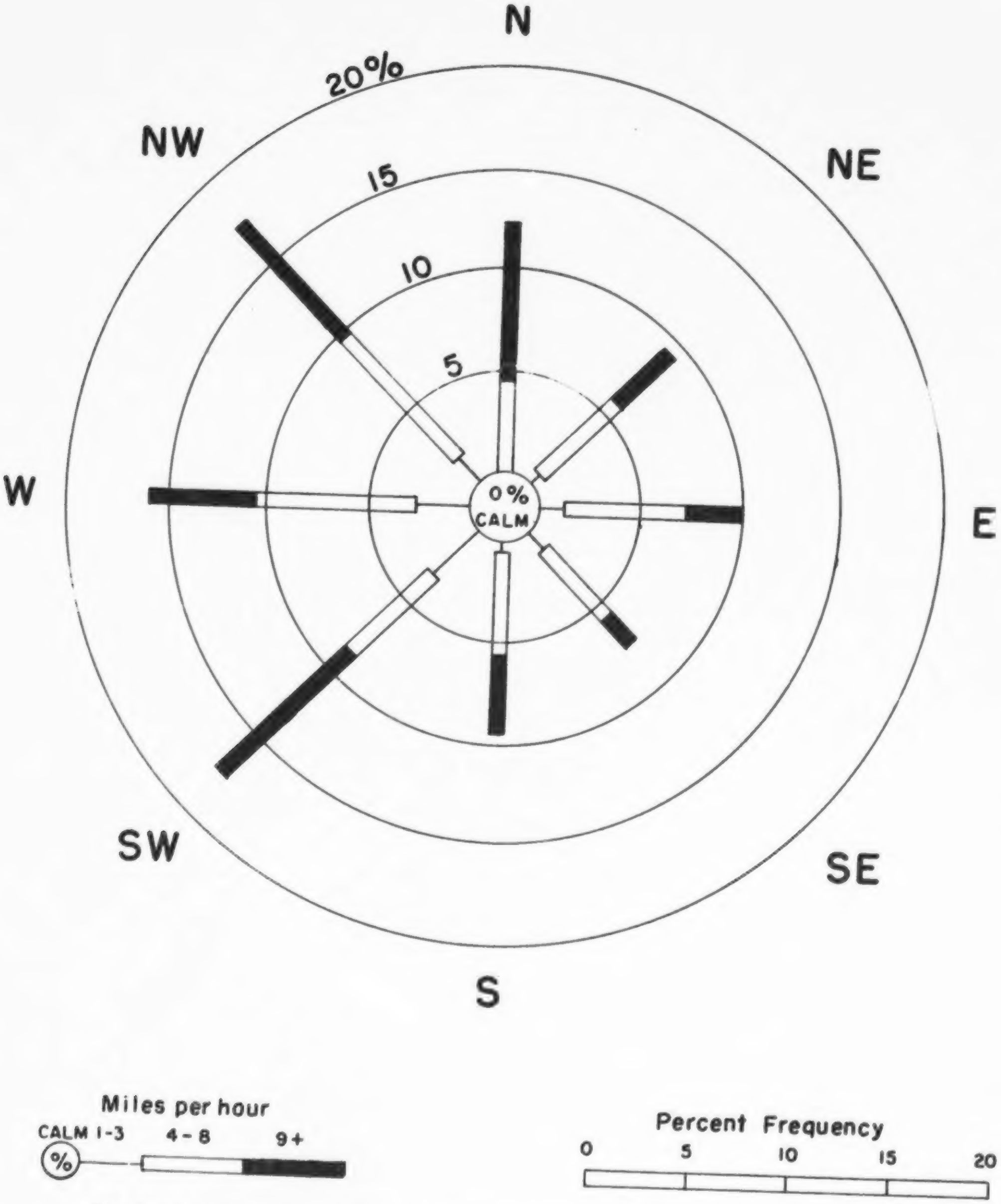


Figure 11c

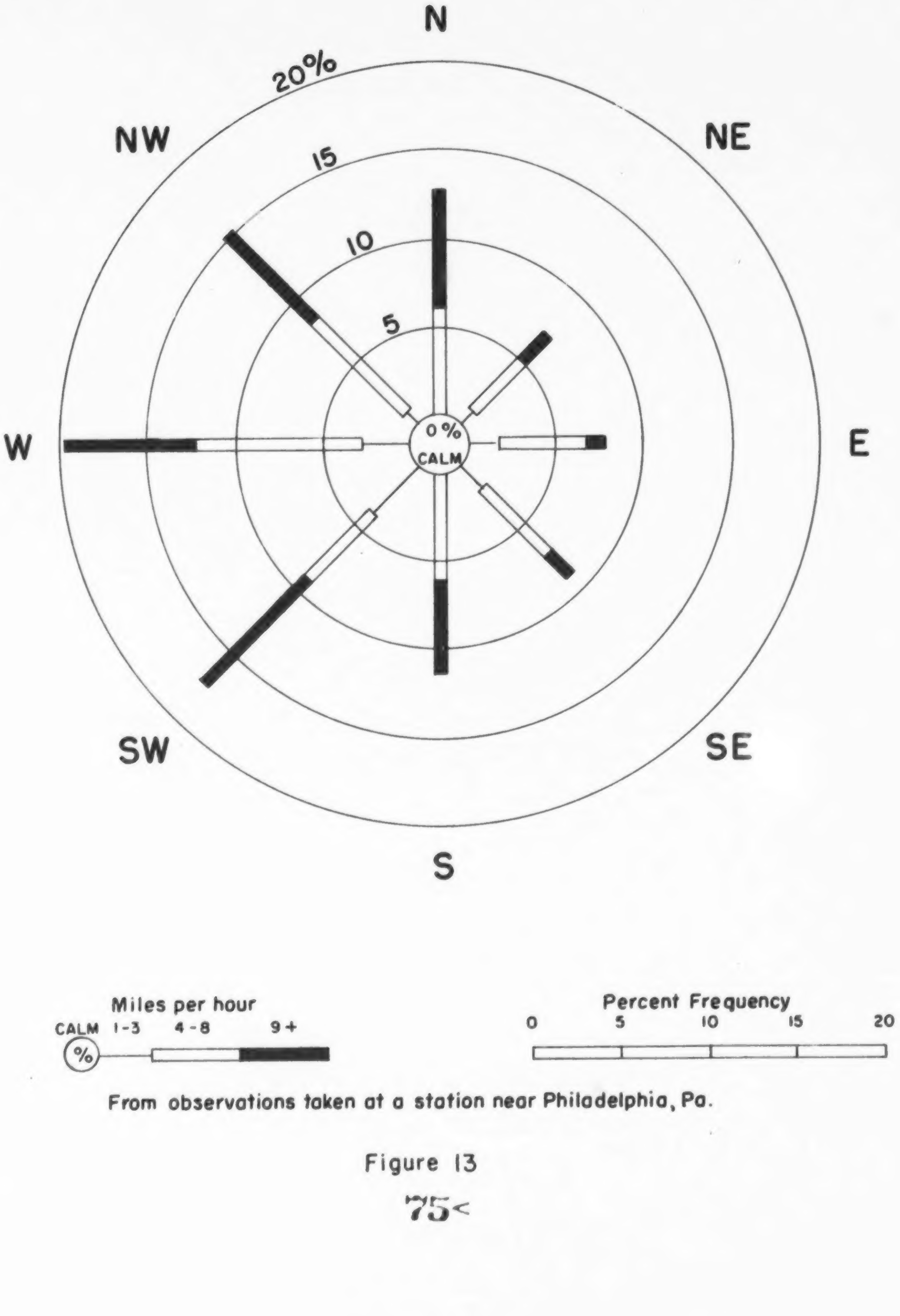
COMPOSITE WIND ROSE, PHILADELPHIA, PENNSYLVANIA DURING INVERSIONS ≥ 2°F PER 600 FT., 1954-56



From observations taken at a station near Philadelphia, Pa.

Figure 12

COMPOSITE WIND ROSE, PHILADELPHIA, PENNSYLVANIA DURING INVERSIONS ≥ 4°F PER 600 FT., 1954-56



From observations taken at a station near Philadelphia, Pa.

Figure 13

40 percent of the time. These figures indicate that during periods of both significant and marked inversions, wind velocities were greater than 4 miles per hour almost 90 percent of the time. Light winds did not occur significantly with periods of inversions.

During the past three years, Drexel Institute of Technology has obtained meteorological observations on the WFIL-KYW tower which they instrumented for the purpose of providing profiles of winds and temperatures up to 890 feet. The tower observations provide the only current data within the 11-county area of temperatures with height up to any significant level and one of only two or three places where upper level winds are available.

Records from the tower have been analyzed by means of high speed calculators. To provide more information on conditions during the important periods of temperature inversions, the computer was programmed to provide wind distributions (both speed and direction) during all times when the temperature difference between the surface and 570 feet equaled or exceeded 2°F. The 570-foot level was the closest to the 600-foot level previously selected, and it was felt that the present study could be related most easily to past studies if conditions were as little changed as possible.

The monthly results of the computer readout during both times of inversions and all times are included in Appendix D which gives the wind rose data (percentage frequency of winds with different speeds and directions) at the 100-ft level based on data for 1965 and 1966. Actual wind roses have been plotted from these data and data from the 570-ft level to show more clearly the distribution of winds with height during inversions. Figures 14a through 14e show the average annual and monthly wind roses obtained at the WFIL-KYW tower during times of inversions ($T_{570} - T_{ground} \geq 2°F$) during the years of record. The data in the Appendix have been given by 10° intervals (36-point compass). To simplify the plotting of the data, they have been grouped by 30° intervals and plotted in figure 14 on a 12-point compass. Wind speed categories have also been combined to 1-5, 6-10 and >10 knots for simplicity.

Figure 14a which shows the annual wind rose during inversion periods at both 100 ft and 570 ft elevation does not differ greatly from conditions shown previously during inversions (figures 12, 13) or during all conditions in 1965 (figure 6) for Philadelphia. The annual tower observations reveal a great difference in wind velocity between 100 ft and 570 ft as would be expected because of the decrease in friction with height. but prevailing wind directions during inversions follow closely the directions found for all weather conditions. One would be hard pressed to find any real difference between the 1965 annual Philadelphia wind rose (figure 6a) and the 570-ft tower wind rose for inversion conditions except in velocity. Comparison of the 100-ft and 570-ft annual roses does show a slight clockwise shifting of the wind with height as would be expected as one moves upward out of the surface friction layer.

Figures 14b through 14e show the monthly patterns of winds at 100 and 570 feet during times of inversions. Most obvious differences between the two levels is the significant increase in wind velocity with height and a decrease in the number of calms experienced. There does not seem to be a really noticeable shift in wind direction with height in many of the months of the year although June and July do illustrate a fairly strong clockwise shift in the direction of greatest frequency (SSW to WSW in June and NNW to N in July).

The actual patterns shown are slightly different from those shown by months on figure 6 for Philadelphia in 1965. While the airport observations included in figure 6 show more northwest (west to north) winds in January, February, March, and April, with a shift to southwest through the late spring and summer, the 570-ft tower observations during inversions show more prevailing southwest winds in January, February, and March, and northwest in April. May and June have prevailing southwest winds, but July and August are somewhat different with winds from the northeast and northwest respectively. September still shows a large number of northwest winds, while September 1965 (figure 6j) shows a high percentage of northeast winds. October through December, based on the tower data, show about the same conditions as were found in those months in 1965 at the Philadelphia airport.

It is clear that wind conditions during times of inversions are quite similar to wind conditions at other times. The fact that temperature increases rather than decreases with height does not result in a different pattern of wind flow near the ground or result from any altered circulation conditions. This does not, of course, contradict the earlier finding that wind conditions during periods of high pollution are significantly different for only a few periods with inversions experience high atmospheric pollution.

Prevailing Wind Flow over the Delaware Basin

Prevailing, or most frequent, monthly wind directions have been obtained from all possible stations within and just outside the study area (using 1965 or longer-term data) in an effort to understand better the monthly flow of wind over the whole basin. These results have been obtained by finding the three adjacent wind directions with the highest total frequency of winds for different velocity categories. The middle wind direction value is then selected as the prevailing wind. Tables 4 and 5 give the result for light wind velocities (generally less than 4 knots) and for all wind velocities for each month at a representative selection of stations. These results are also shown by means of arrows on figures 15 and 16 .

Figure 15, which shows the monthly variation in wind flow (without regard to wind speed), emphasizes the changes on the previously described wind roses. In the winter months (November through March), winds at almost all stations are predominantly from the WNW or NW. This pattern begins to break up in April The coastal stations of Atlantic City and Barnegat have southerly winds while north winds are found at Philadelphia, Marcus Hook, and Delaware City (these based on 1965 results only). As the summer season begins in May, there is a general shift in the wind direction to southwesterly over the whole area with the exception of a southeast wind at Belmar and a northwest wind at Barnegat (both long-term averages). As the summer progresses, the winds shift slightly more to the south-southwest and are quite uniform over the whole area

AVERAGE ANNUAL WIND ROSES
WFIL-KYW TOWER, PHILADELPHIA, 1964-66
DURING PERIODS OF TEMPERATURE INVERSIONS

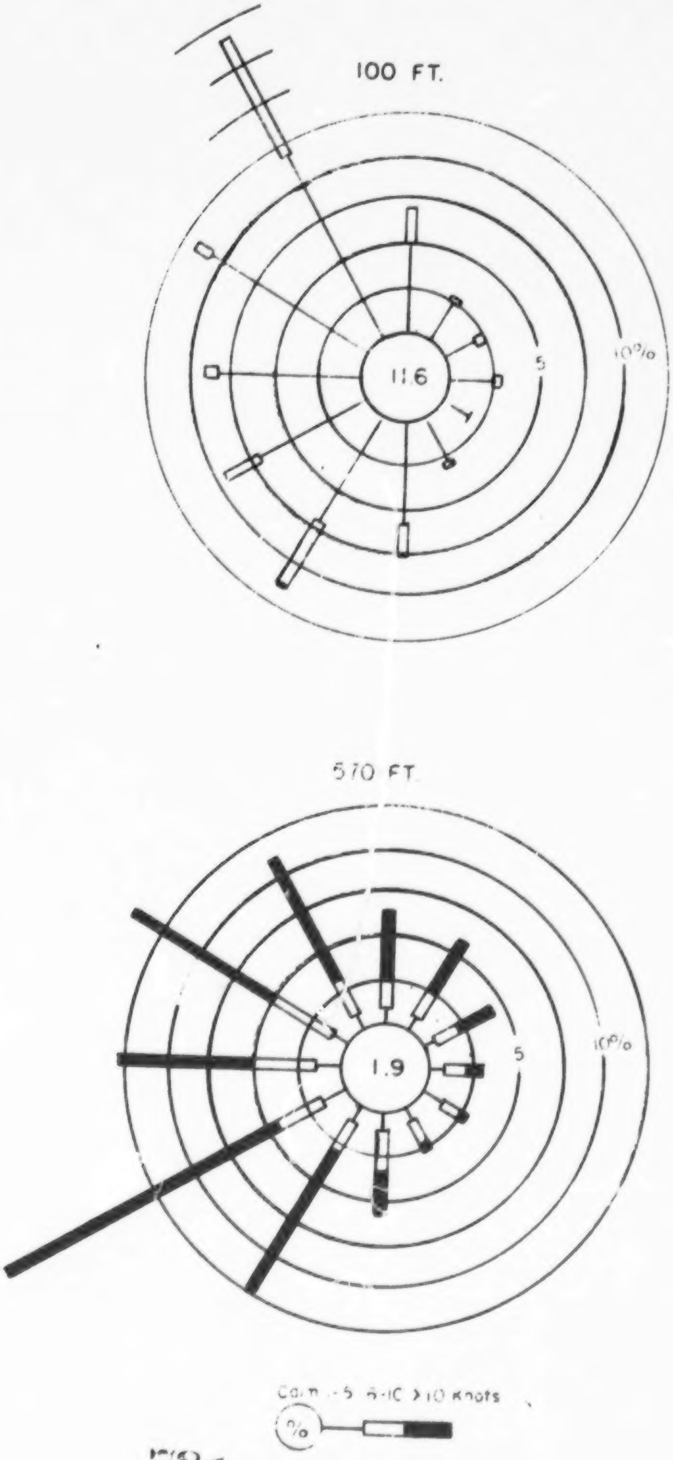


Figure 14a

AVERAGE MONTHLY WIND ROSES, WFIL-KYW TOWER, PHILADELPHIA, 1964-66, DURING PERIODS OF TEMPERATURE INVERSIONS

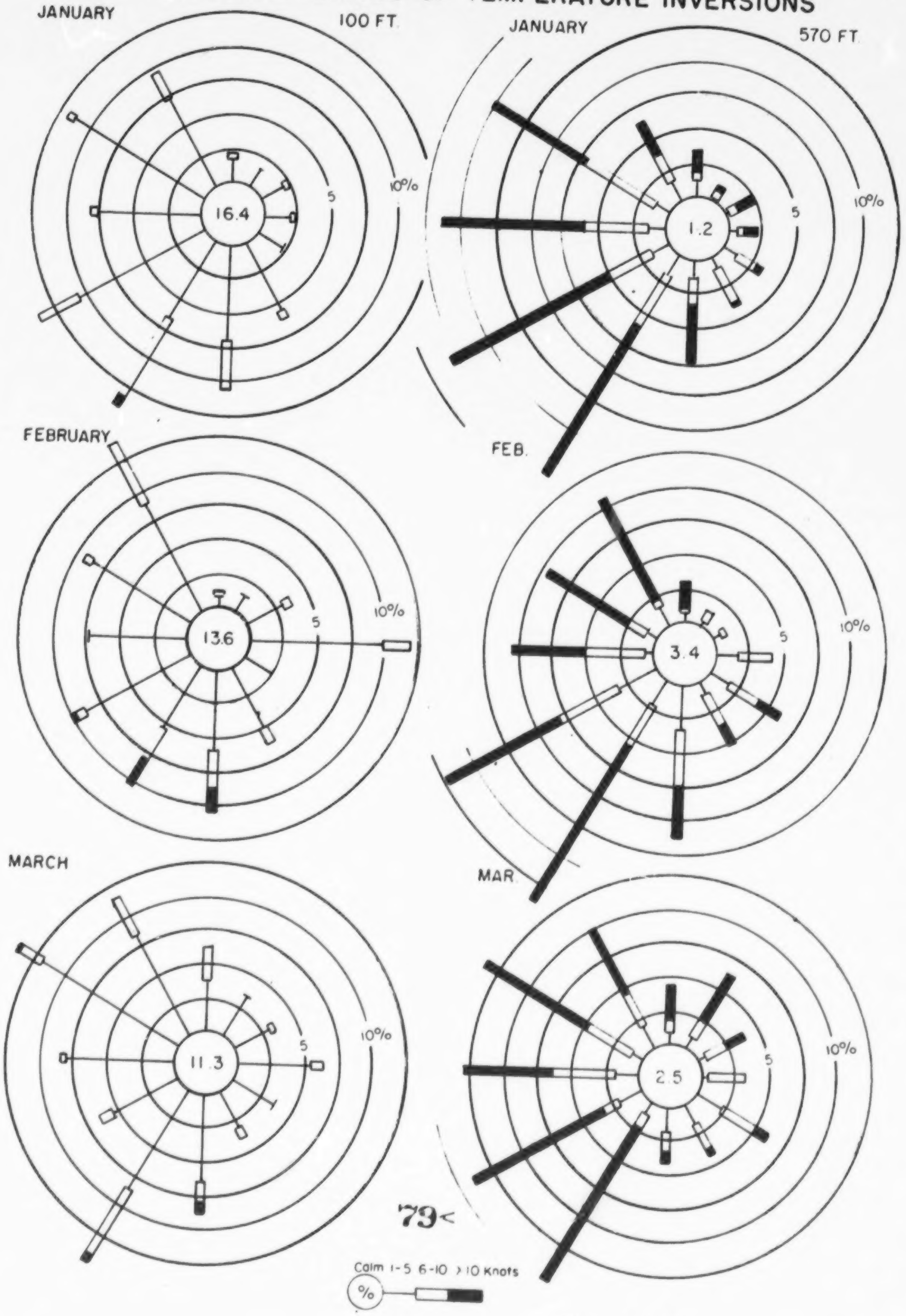


Figure 14 b

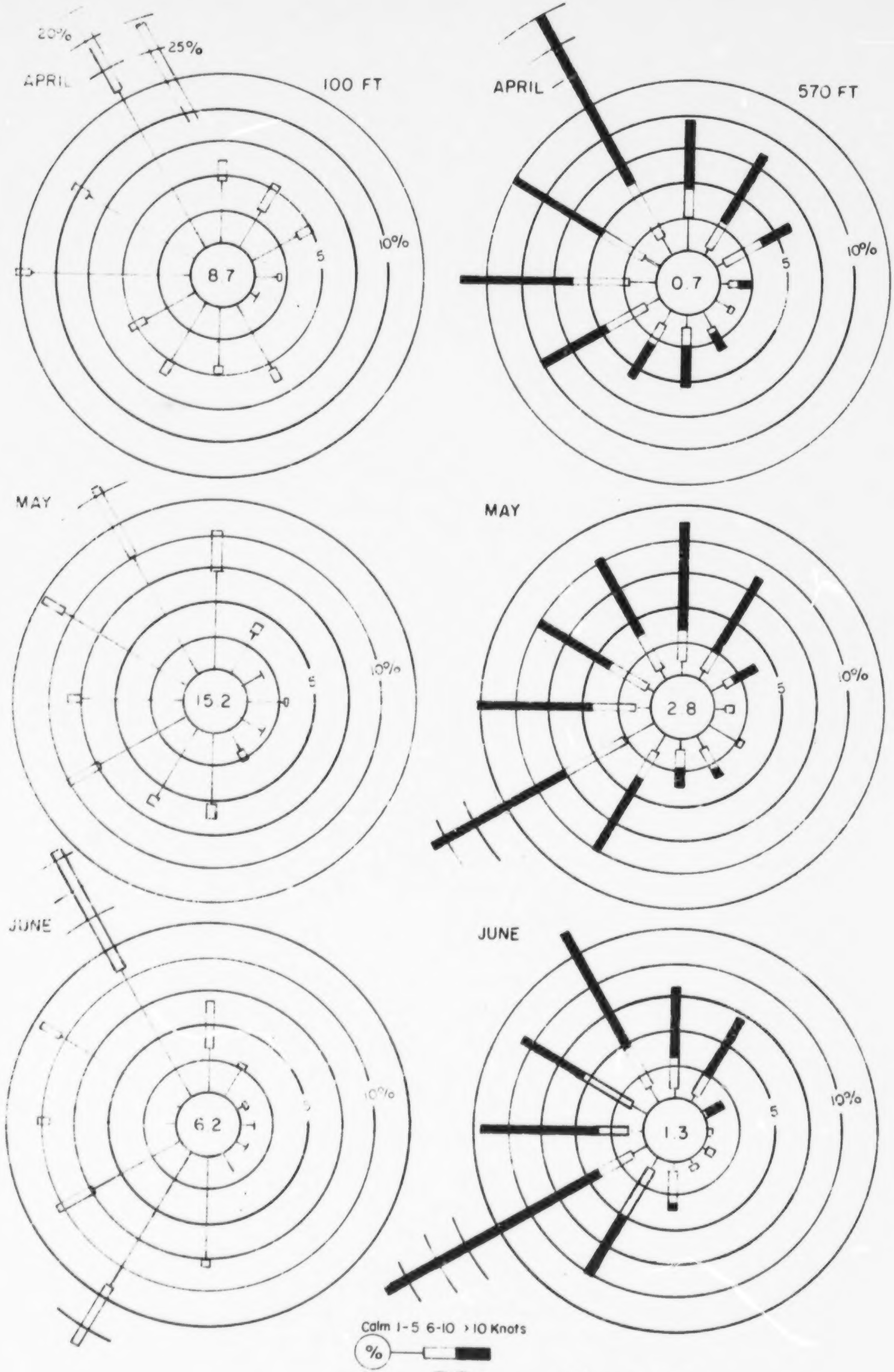

20%
25%
APRIL
100 FT
8.7
5
10%
APRIL
570 FT
0.7
5
10%
MAY
15.2
5
10%
MAY
2.8
5
10%
JUNE
6.2
5
10%
JUNE
1.3
5
10%
Calm 1-5 6-10 >10 Knots
%

Figure 14 c

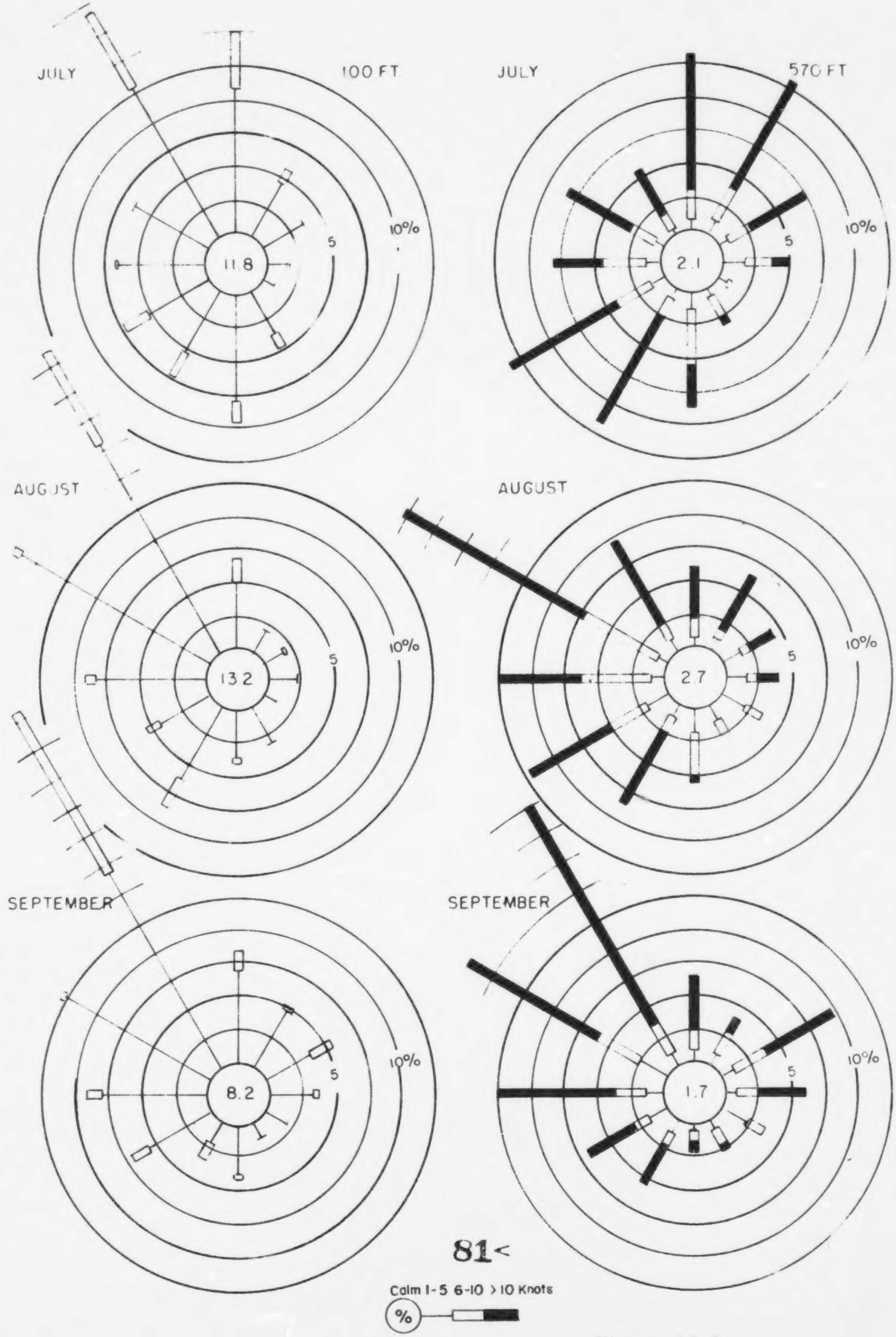

JULY
100 FT
11.8
5
10%
JULY
570 FT
2.1
5
10%
AUGUST
13.2
5
10%
AUGUST
2.7
5
10%
SEPTEMBER
8.2
5
10%
SEPTEMBER
1.7
5
10%
Calm 1-5 6-10 >10 Knots
%

Figure 14 d

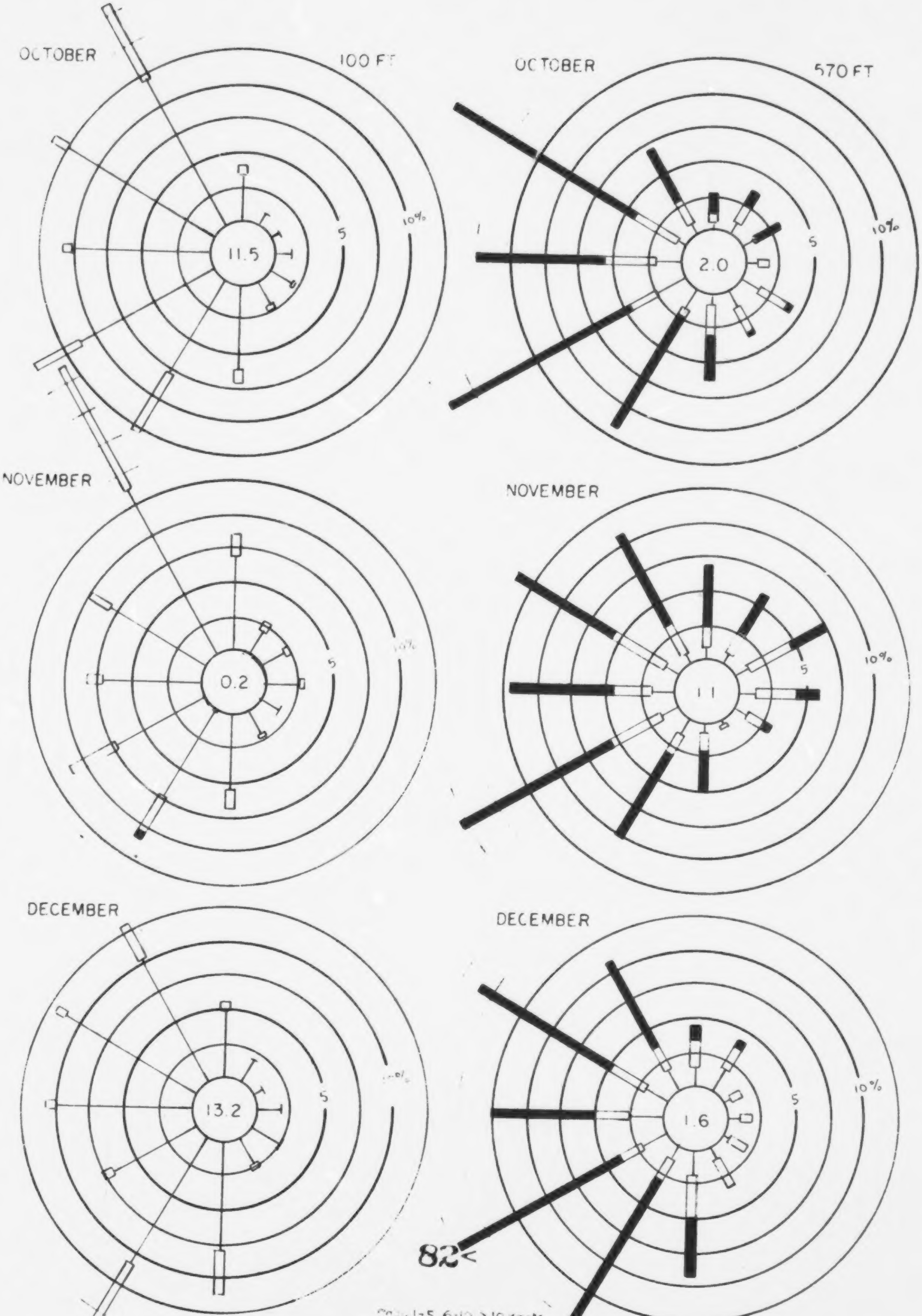

OCTOBER
100 FT
11.5
5
10%
OCTOBER
570 FT
2.0
5
10%
NOVEMBER
0.2
5
10%
NOVEMBER
1.1
5
10%
DECEMBER
13.2
5
10%
DECEMBER
1.6
5
10%
1-5 6-10 > 10 knots
1%

Figure 14 e

MONTHLY VARIATION IN PREVAILING WIND DIRECTION (ALL VELOCITIES) AT DELAWARE VALLEY STATIONS (1965 AND LONGER PERIOD DATA)

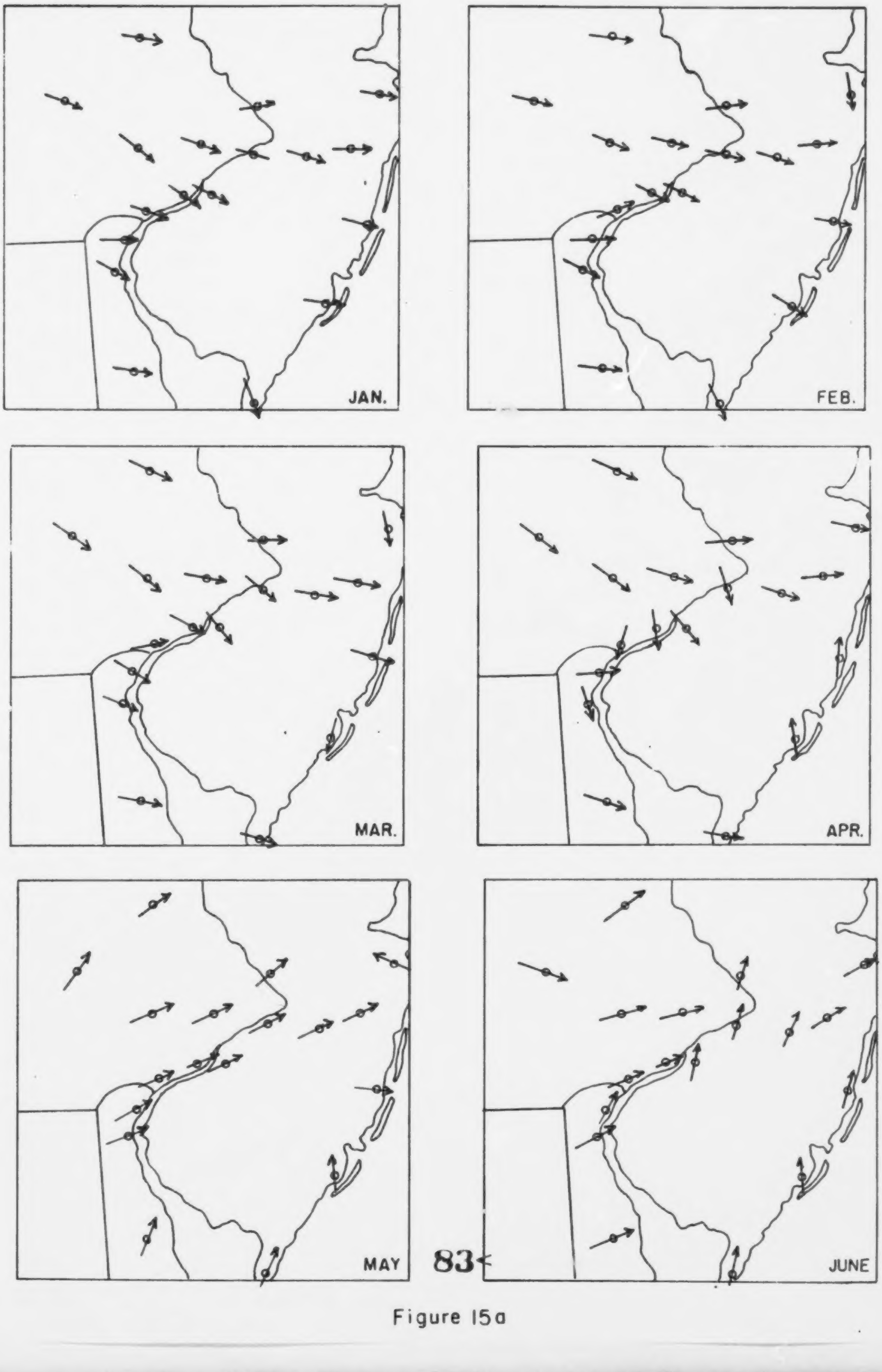

JAN.
FEB.
MAR.
APR.
MAY
JUNE

Figure 15a

MONTHLY VARIATION IN PREVAILING WIND DIRECTION (ALL VELOCITIES) AT DELAWARE VALLEY STATIONS (1965 AND LONGER PERIOD DATA)

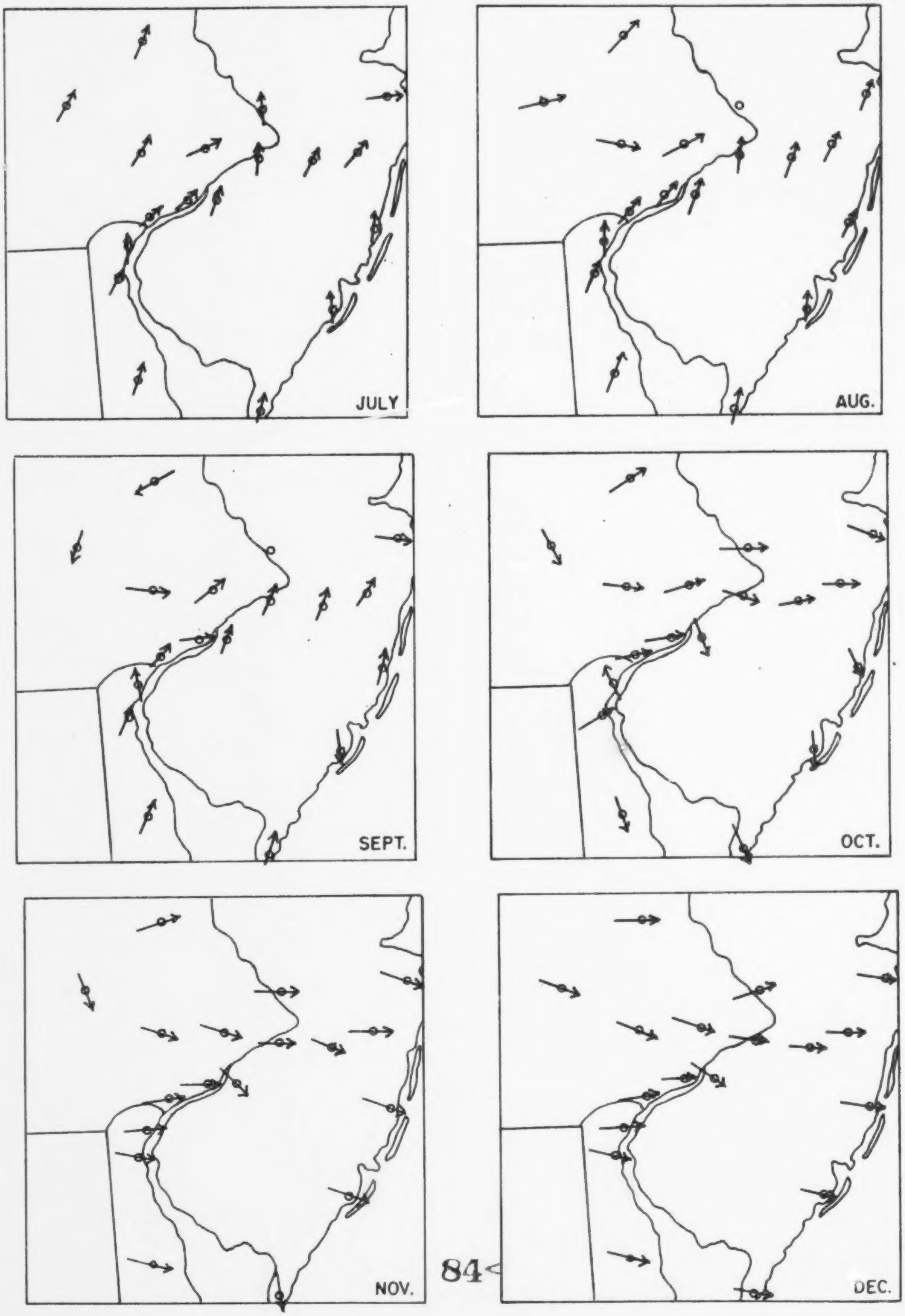

JULY
AUG.
SEPT.
OCT.
NOV.
DEC.

Figure 15b

MONTHLY VARIATION IN PREVAILING WIND DIRECTION (WIND SPEED < 4 KTS) AT DELAWARE VALLEY STATIONS (1965 AND LONGER PERIOD DATA)

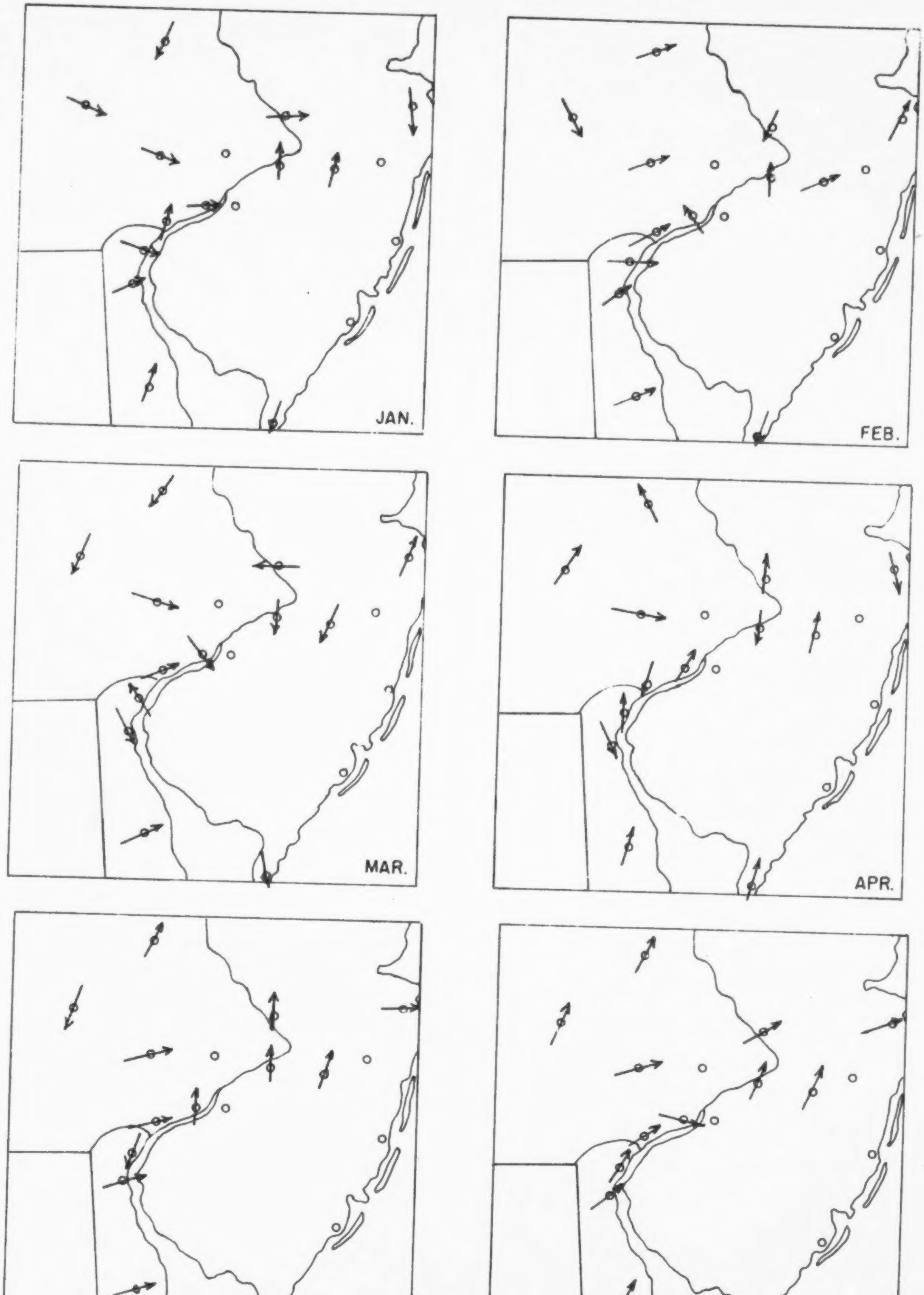

JAN.
FEB.
MAR.
APR.
MAY
JUNE

Figure 16a

MONTHLY VARIATION IN PREVAILING WIND DIRECTION (WIND SPEED < 4 KTS) AT DELAWARE VALLEY STATIONS (1965 AND LONGER PERIOD DATA)

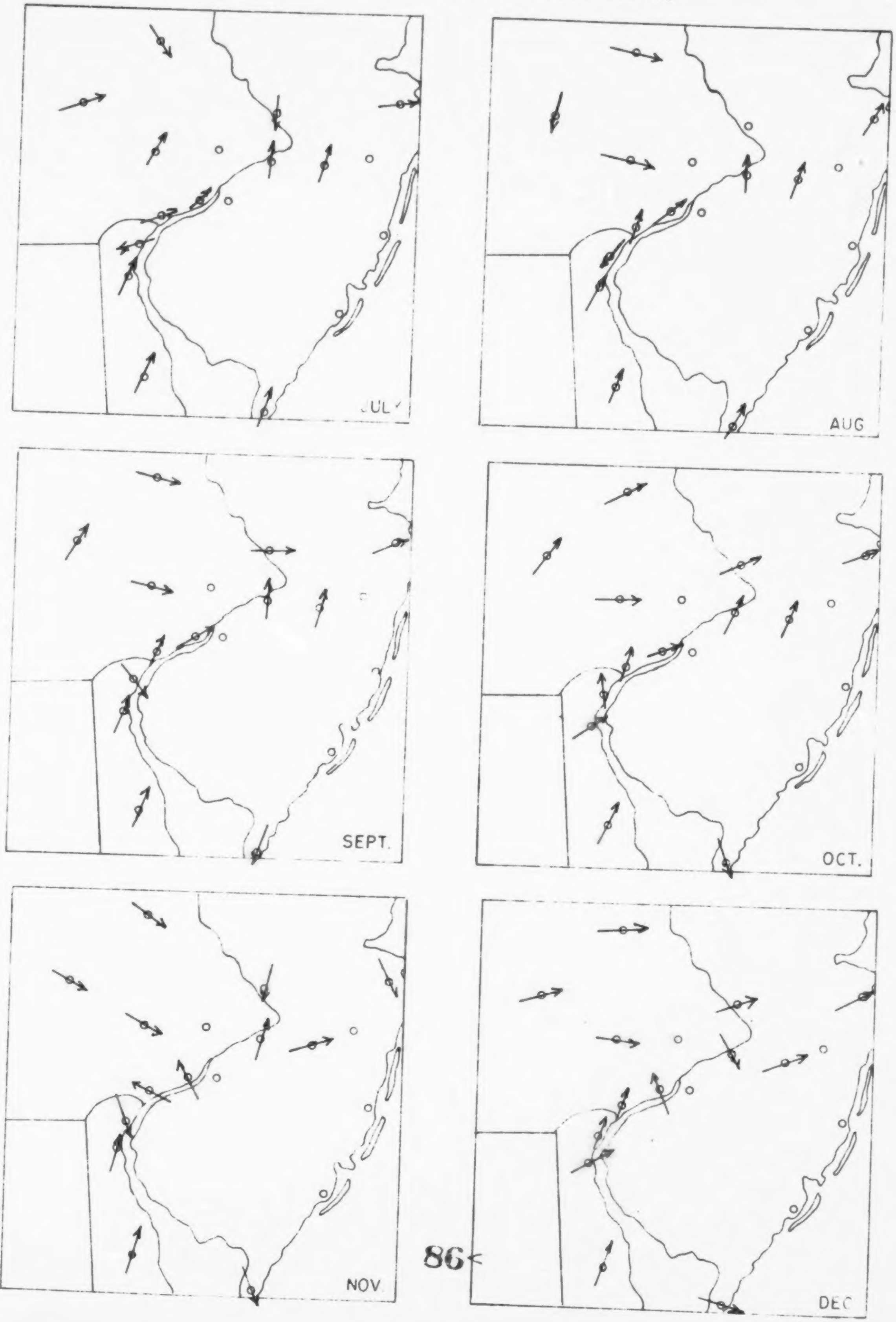

JULY
AUG
SEPT.
OCT.
NOV.
DEC.

Figure 16b

Table 4

Prevailing Wind Directions for Light Winds (<≈4 kts) at Delaware Valley and Nearby Stations

Station*	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1	NNE (1.7)**	WSW (2.0)	NE (1.4)	SSE (.9)	SSW (1.8)	SSW (2.3)	NW (2.7)	WNW (1.7)	WNW (2.4)	SW (1.8)	NW (2.3)	W (8.0)	W (1.7)
4	N (1.0)	SSE (1.7)	SSE (1.2)	N (1.4)	W (3.9)	WSW (5.8)	W (3.8)	SSW (5.4)	WSW (10.6)	WSW (9.4)	NNW (8.6)	WSW (7.4)	WSW (4.6)
5	S (10.3)	S (9.1)	N (9.6)	N (11.1)	S (12.3)	SSW (10.8)	S (13.2)	S (11.9)	S (10.5)	SSW (7.4)	SSW (7.8)	NNW (10.6)	S
7	NNE (3.4)	NNE (3.2)	NNW (1.8)	SSW (2.1)	ENE (2.9)	SSW (4.4)	SSW (3.4)	SW (3.0)	NNE (3.7)	NNW (3.2)	NNW (2.4)	WNW (3.4)	
8	SSW (2.4)	WSW (1.9)	WSW (1.7)	SSW (1.8)	WSW (2.2)	SSW (3.4)	SSW (4.6)	SSW (4.8)	SSW (3.4)	SSW (2.5)	SSW (2.9)	SSW (2.9)	SSW (2.9)
10	SSW (9.0)	SW (5.7)	WSW (10.4)	NNF (7.5)	WSW (8.6)	WSW (8.9)	WSW (10.0)	SSW (10.8)	SSW (9.0)	SSW (8.4)	ESE (5.6)	SSW (4.3)	SSW (7.2)
11	SSW (2.5)	WSW (2.1)	NNE (1.8)	SSW (1.6)	SSW (2.5)	SSW (4.0)	SSW (5.2)	SSW (4.9)	SSW (3.7)	SSW (3.2)	WSW (2.8)	WSW (2.9)	SSW (3.1)
12	W (4.5)	NNE (2.8)	E (3.9)	S (2.9)	S (3.0)	WSW (6.4)	N (5.7)	- -	W (6.0)	WSW (8.4)	NNE (4.7)	WSW (4.2)	WSW (4.0)
13	WSW (13.4)	SW (11.9)	NNW (10.9)	NNW (10.5)	WSW (13.1)	SW (14.8)	SSW (13.0)	SSW (20.0)	SSW (21.3)	SW (22.6)	SSW (12.4)	SW (14.3)	SW (2.3)
14	W (2.9)	SE (2.0)	NW (2.4)	SW (2.3)	S (4.4)	WNW (2.2)	SW (5.1)	SW (1.9)	SW (2.3)	WSW (3.5)	SE (1.9)	SSE (2.9)	SW (2.3)
17	WNW (14.2)	WSW (7.4)	WNW (12.3)	WNW (9.7)	WSW (24.1)	WSW (20.9)	SSW (18.3)	WNW (29.6)	WNW (17.0)	WNW (34.1)	WNW (28.0)	WNW (30.4)	WNW (18.4)
18	WNW (3.1)	NNW (2.2)	NNE (1.7)	SSW (1.6)	NNE (2.3)	SSW (2.2)	WSW (2.3)	NNE (3.6)	SSW (3.0)	SSW (4.0)	WNW (2.3)	WSW (3.2)	WSW (2.2)
19	WNW (2.4)	W (1.3)	SE (.8)	S (.4)	NNE (1.6)	SSW (1.6)	ENE (.8)	NE (.8)	NW (2.1)	SSE (2.8)	NNW (1.7)	SSW (2.8)	WSW (.9)

---

* Identification of stations used in tables 4 and 5:

1. Allentown
2. Atlantic City
3. Barnegat City
4. Belmar
5. Burlington
6. Camden
7. Cape May
8. Dover
9. Lakehurst
10. Marcus Hook
11. McGuire AFB
12. Mercer
13. Newcastle (S)
14. Philadelphia
15. Mustin Field
16. Willow Grove
17. Phoenixville
18. Reading
19. Wilmington

**Total frequency in three adjacent directions - one on each side of indicated direction.

Table 5

Prevailing Wind Directions (All Wind Speeds) at
Delaware Valley and Nearby Stations

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1	WNW (38.8)*	WNW (34.5)	NW (36.1)	NW (29.4)	SW (41.0)	SW (38.7)	SSW (27.6)	SW (30.2)	ENE (25.1)	SW (41.0)	WSW (31.3)	W (38.3)	W (29.6)
2	WNW (28.8)	NW (36.8)	NE (28.9)	S (25.4)	S (27.7)	S (31.8)	S (35.4)	S (27.6)	NNW (22.4)	N (23.2)	WNW (31.2)	WNW (36.9)	S (23.9)
3	WNW (48.0)	WNW (48.0)	WNW (49.0)	SSW (27.0)	WNW (29.0)	SSW (32.0)	SSW (43.0)	SSW (36.0)	SSW (31.0)	NNW (34.0)	WNW (39.0)	WNW (39.0)	WNW (32.4)
4	WNW (39.4)	NNE (28.2)	NNW (35.4)	WNW (33.4)	ESE (28.6)	WSW (27.1)	W (30.9)	SSW (22.3)	WNW (25.1)	WNW (29.8)	WNW (28.7)	WNW (39.3)	WNW (27.4)
5	WNW (34.3)	WNW (36.6)	NW (34.4)	NNW (30.0)	SW (31.4)	SSW (31.6)	S (38.3)	S (38.1)	SSW (27.1)	WNW (33.4)	W (30.2)	WNW (30.4)	WNW (
6	NW (28.0)	NW (33.0)	NW (28.0)	NW (26.0)	SW (26.0)	SSW (31.0)	SSW (32.0)	SSW (24.0)	SSW (23.0)	NNW (24.0)	NW (28.0)	NW (31.0)	NW (22.1)
7	NNW (39.2)	NNW (40.7)	WNW (25.9)	WNW (33.3)	SSW (40.6)	SSW (41.7)	SSW (45.7)	SSW (44.6)	SSW (25.8)	NNW (29.4)	NNW (40.6)	WNW (37.0)	SSW (
8	WNW (35.5)	WNW (33.2)	WNW (30.3)	WNW (26.4)	SSW (24.6)	WSW (26.6)	SSW (30.6)	SSW (25.3)	SSW (22.9)	NNW (22.7)	WNW (31.1)	WNW (33.5)	WNW (24.9)
9	W (37.2)	W (36.3)	WNW (36.2)	W (29.4)	WSW (25.1)	WSW (26.8)	SW (29.5)	SW (23.1)	SW (21.3)	W (24.7)	W (33.7)	W (38.9)	W (28.8)
10	WNW (29.4)	WSW (34.4)	WSW (40.2)	NNE (33.4)	WSW (49.3)	WSW (52.4)	SW (50.4)	SW (44.2)	SW (34.2)	WSW (47.2)	WSW (34.8)	WSW (40.9)	WSW (39.5)
11	WNW (34.5)	WNW (35.1)	WNW (30.7)	WNW (25.5)	WSW (23.0)	SSW (27.3)	SSW (30.4)	SSW (25.5)	SSW (22.3)	WSW (21.1)	WNW (30.3)	W (34.0)	WNW (24.5)
12	WSW (40.3)	WSW (44.1)	W (35.7)	W (28.0)	SW (35.1)	SSW (36.0)	SSE (31.3)	- -	ENE (28.7)	W (47.9)	W (37.5)	WSW (42.9)	WSW (33.2)
13	NW (35.6)	NW (30.6)	NW (38.5)	NNW (31.6)	WSW (25.4)	WSW (39.4)	SSW (30.0)	SSW (35.4)	SSW (30.8)	SW (40.1)	WNW (30.9)	WNW (28.5)	WNW (25.3)
14	WNW (31.0)	WNW (35.7)	NW (33.4)	NNW (28.4)	WSW (39.6)	SW (44.3)	SW (37.8)	SW (32.8)	WSW (25.5)	WSW (43.4)	W (30.8)	WSW (36.4)	WSW (31.4)
15	WNW (30.0)	NW (31.2)	NNW (27.8)	WSW (26.9)	WSW (27.9)	WSW (33.5)	WSW (34.9)	WSW (26.1)	WSW (24.3)	WSW (26.1)	WNW (29.1)	WNW (34.5)	WNW (26.1)
16	WNW (34.5)	WNW (33.0)	WNW (35.4)	WNW (28.9)	WSW (25.2)	WSW (26.4)	WSW (25.6)	WSW (20.5)	SW (21.4)	WSW (20.5)	WNW (32.6)	WNW (34.6)	WNW (26.8)
17	NW (29.1)	NW (26.6)	NW (30.7)	NW (25.5)	WSW (30.9)	WSW (27.6)	SSW (26.4)	WNW (33.8)	WNW (18.2)	WNW (40.7)	WNW (35.5)	WNW (34.9)	WNW (27.0)
18	WNW (30.6)	WNW (30.4)	NW (24.7)	NW (24.0)	SSW (20.9)	WNW (18.9)	SSW (23.9)	WSW (20.4)	NNE (22.3)	NNW (22.2)	NNW (29.4)	WNW (39.8)	WNW (24.1)
19	W (40.0)	W (33.4)	NW (40.0)	W (31.9)	SW (28.8)	SSW (37.8)	S (30.8)	S (31.2)	S (26.0)	SSE (34.0)	W (32.4)	W (35.6)	W (30.7)

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* Total frequency in three adjacent directions - one on each side of indicated direction.

September presents a more confused pattern. Not only is the summer pattern of southwesterly winds in the process of breaking down, but the earlier wind analysis pointed out that September 1965 was fairly unique with many more northeasterly winds than is normally the case. Thus the September pattern shows northeasterly winds at Reading, Allentown, and Mercer (1965 results) with west or southwest winds still prevailing at the other stations. October is also a month of transition with generally west winds prevailing but with northwest winds along the coast and at Camden and Reading and southeast winds at Wilmington. These exceptions to the general rule, in an area as level as the Delaware Valley, result primarily from the summation process when winds are fairly evenly distributed from several directions. For example, while winds were from the south, south-southeast, and southeast directions 34 percent of the time in October at Wilmington, they were from the west (west-southwest through west-northwest) 30.4 percent of the time. Thus both directions were almost equally favored, and the south-southeast arrow is entered only because that wind occurred 4 percent more frequently than did the west wind which would have agreed better with prevailing winds at nearby stations. Thus reference should be made to the wind roses (figure 6) and the general wind flow pattern rather than to the individual arrows in interpreting these diagrams.

Figure 16 shows the monthly variation of wind direction for light winds only (less than 4 kts) in the Delaware Valley area. The seasonal patterns for light winds are more variable than the patterns for all wind velocities because a) light winds are more variable and more subject to local influence than stronger winds, and b) the number of light winds is small at most stations so that just a few winds from one direction can influence the results unduly. While prevailing wind directions (all speeds) given on table 5 occurred 20 to 40 percent of the time, prevailing directions for light wind cases often constituted less than 5 percent of the total wind observations.

The arrows indicated on figure 16 show marked changes between adjacent stations and no general tendency over the whole area. During many months of the year, the Wilmington arrow seemed to be at odds with the other arrows around it while the Mercer and Burlington arrows are often opposed. These differences should not be construed as errors in wind observations but only as the result of very small differences in a relatively small total of light winds and thus really of little significance. In four months of the year, the prevailing light wind direction at Wilmington comprises .8 percent or less of the total wind observations and therefore could hardly be called prevailing.

Figures 17 and 18 give the average annual wind flow over the area based on all winds and light winds for all twelve months of the year. Tentative streamlines have been included to increase the clarity. The general conclusion that can be drawn from these two diagrams is that west to northwest winds prevail more frequently when all wind velocities are considered and west to southwest winds prevail when only light winds are considered. Thus a prevailing drift of winds from the southwest to the northeast is most commonly expected when light winds are experienced although one must be careful not to generalize too much. Under light wind conditions, when pollution might possible be more significant, the slow movement of materials northeast along the Delaware Valley from Wilmington to Chester to Philadelphia and to Trenton might be anticipated more times than any other flow, thus increasing the possibilities of lowered air quality.

The Question of Airsheds or Air Basins

One aspect of wind flow that always seems to arise when air pollution is discussed is the question of airsheds or air basins. Laymen have the idea that in certain geographic basins or regions, the lower atmosphere can be treated as an entity, separate from the air in the next adjacent basin just as precipitation and water runoff can be considered by watersheds in hydrology. In mountainous terrain, such as in the Rockies or along certain portions of the west coast, the concept has some validity but in a flat open area such as the eastern seaboard of the United States, the analogy to watersheds becomes much more tenuous. It is clear from a study of the pattern of air flow over the Delaware Valley area in relation to the topographic features of the region that the concept of an airshed has no real significance.

The eastern seaboard area of the country, covering the region from the Appalachian-Allegheny mountain ridges eastward to the coast has to be considered as one continuous atmospheric area. There are no topographic features to break the north-south extent of this region from Massachusetts to essentially the Gulf of Mexico. Even if temperature differences and general circulation conditions provide certain opportunities to break the long north-south extent of the region, it is clear that at least the area from Virginia north to Massachusetts and from the coast westward to the Appalachian-Allegheny region may be considered as a fairly continuous, uniform region without barriers or divides as far as the flow of air is concerned. Pollutants introduced into the air at one place can move without topographic hindrances to any other area in this large geographic area (provided wind conditions are correct).

It must be recognized, of course, that there still will exist within this broad geographic region, restricted areas where intensification of pollution conditions will occur as a result of local topographic features. These areas are of such small extent (restricted portions of river valleys, isolated basins in rolling terrain) that they can hardly be called airsheds on their own and they produce only localized eddies or backwaters in the general air flow over the broader basin. There is no easy way to identify or study these restricted areas without detailed, time-consuming and expensive topo-climatic surveys, but they are of only limited importance in the whole problem of meteorology and air pollution over the Delaware Valley area.

It is clear from a study of the topography and air flow in the area that no portion of the 11-county study area is any more or less prone to lowered air quality as a result of wind flow conditions. Certain regions do have more incidence of pollution but this is because of the distribution of pollution sources rather than because of the existence of circulation or topographic conditions.

PREVAILING ANNUAL WIND DIRECTION (ALL VELOCITY WINDS)

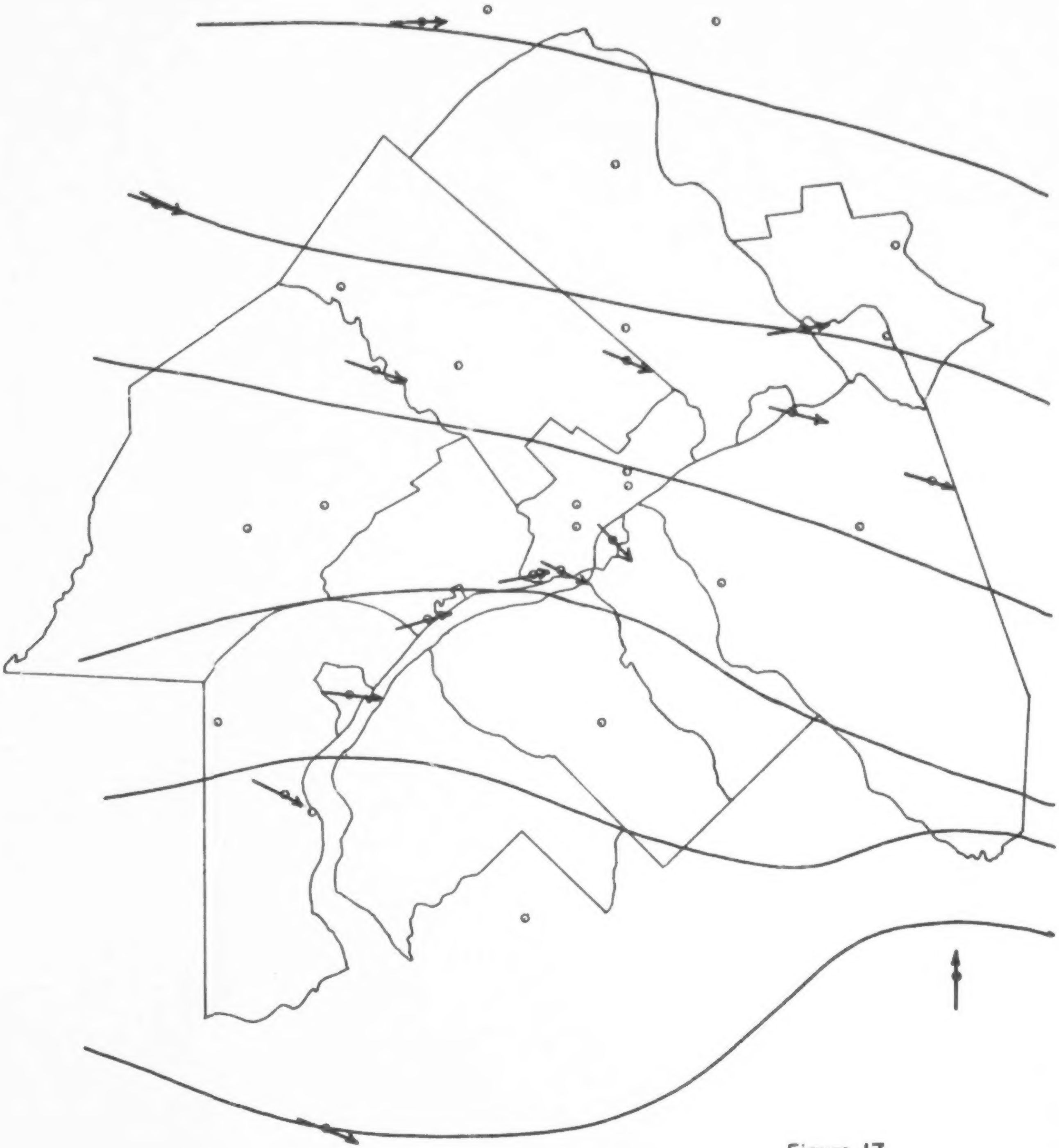

Figure 17

PREVAILING ANNUAL WIND DIRECTION (WINDS BELOW 4 KTS.)

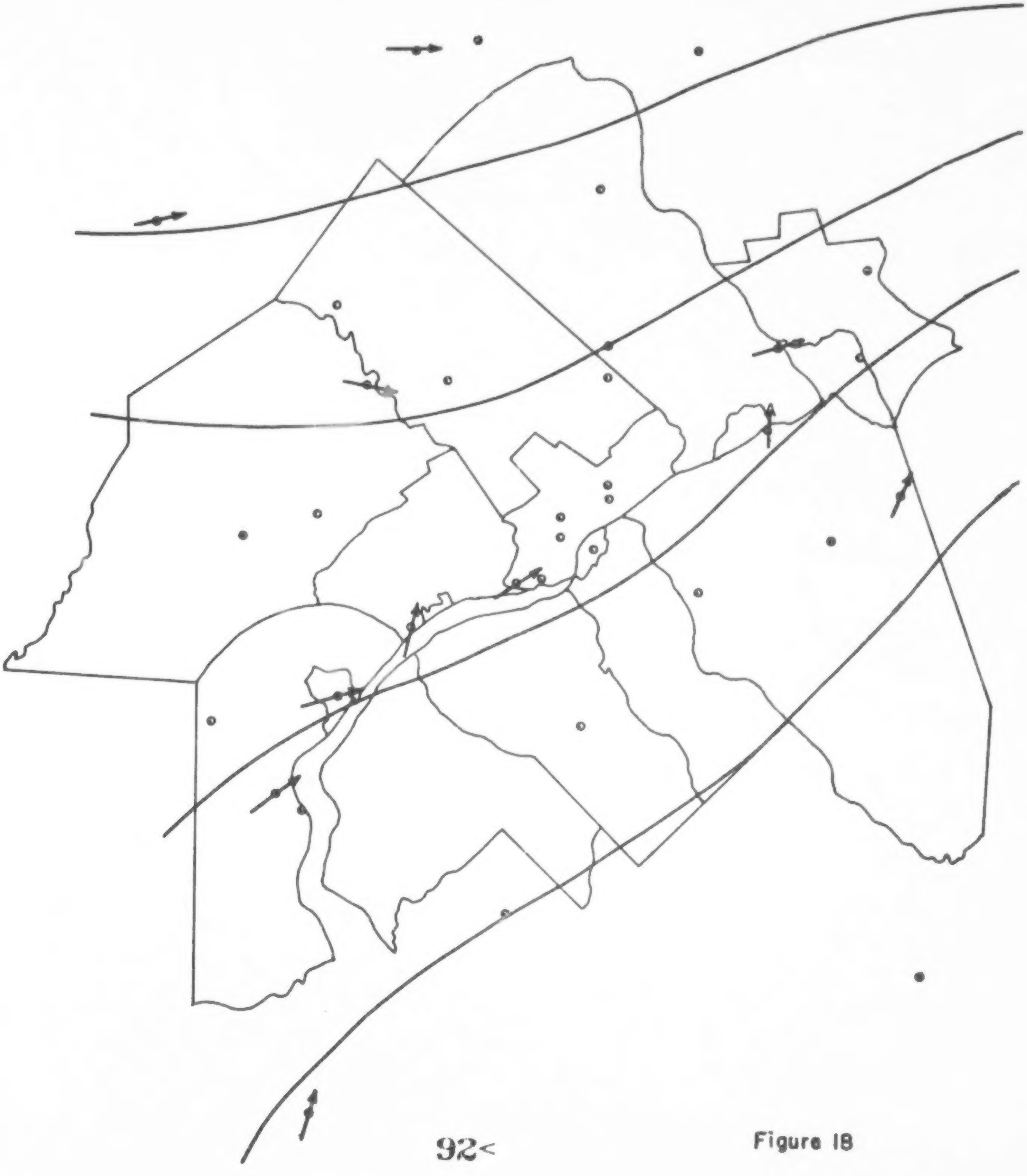

Figure 18

CHAPTER IV. ANALYSIS OF ATMOSPHERIC STABILITY IN THE DELAWARE VALLEY

Significant air pollution really only exists when the quality of the air deteriorates to the point that it has some detrimental effect on life in any of its forms or on the economy of a community. This occurs when the ability of the air to disperse the usual load of contaminants introduced into the air through the daily cycle of living is limited by some set of meteorologic circumstances or when the usual load of contaminants is increased as a result of population or industrial expansion in a particular area beyond the atmosphere's natural ability to handle these contaminants. We are concerned with the first set of circumstances here, relating to the possible existence of limiting meteorological conditions.

Miller (1967) has stated:

> "The two most important meteorological variables that determine the dilution of air pollutants over urban areas are (1) the vertical depth through which the dispersion takes place (i.e. the 'mixing' depth), and (2) the mean transport wind speed in that layer." (p. 35)

Investigations of the vertical depth through which the dispersion takes place have, in general, followed one of two fairly related lines: a) studies of frequency, duration, thickness, and stability of temperature inversions in the atmosphere, and b) studies of the frequency, depth, and persistence of afternoon mixing depths.

The present study of air pollution and meteorology in the Delaware Valley has investigated both of these aspects of the vertical depth through which mixing of pollutants can take place.

Seasonal and Diurnal Variations in Inversions at Nearby Stations

C. R. Hosler (1961) reported on the low-level inversion frequency in the United States. Since he investigated the same type of data that we must use in the present study, his results are of considerable significance in the course of our own work. Hosler, using two years of radiosonde data (balloon-borne temperature and moisture data radioed to earth) from all available stations, studied the variation in the frequency of inversions and/or isothermal conditions up to 500 feet above the station elevation for four time periods during the day. The inversion data were summed by seasons (winter, spring, summer, and fall). The observations for the eastern part of the country were obtained at 0700, 1000, 1900, and 2200 local standard time. Unfortunately these time periods do not give a good sample of the frequencies of inversions during the afternoon period when they should be at a minimum. At the same time, during the summer periods the available data probably miss the period of maximum inversions which would come earlier than 0700. However, the distributions are such that one can obtain an indication of the course of temperature inversions in the lowest air layer by seaons of the year.

Hosler's results for stations near our Delaware Valley area are summed up in table 6. The results are given in terms of frequency of inversion or isothermal conditions expressed as a percent of the total hours during which these conditions might possibly exist. As we would anticipate, the lowest number of inversions are found at the 1000 LST sampling period. Generally speaking, the frequency of inversions increases toward night with a maximum coming either at the 2200 or the 0700 LST period. New York fairly consistently showed a smaller number of inversions at the 0700 period than at the 2200 period, while the other three stations consistently had more inversions at 0700 than at 2200. The Pittsburgh, Washington, and Norfolk data indicate that more than 50 percent of the time inversions existed at the 0700 period. The inversion frequency was only about 30 percent at New York

Table 6

Percent Frequency of Inversions or Isothermal Conditions
Below 500 Ft.[1]
(percent of total hours)

LST	1000	1900	2200	0700
New York				
Winter	7	18	21	24
Spring	3	36	36	32
Summer	1	22	45	21
Fall	1	24	48	30
Pittsburgh				
Winter	24	20	33	41
Spring	6	5	34	68
Summer	1	4	55	64
Fall	15	25	56	62
Washington				
Winter	22	30	44	48
Spring	5	12	42	51
Summer	2	5	47	57
Fall	8	34	56	59
Norfolk				
Winter	28	40	28	48
Spring	8	15	31	50
Summer	3	9	21	45
Fall	21	30	29	50

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[1] Adapted from Hosler, C. R., 1961, Appendix, pp. 333-339.

The seasonal variation of inversion frequency is even more interesting. At 1000 LST, the maximum number of inversions are found during the winter at all four stations with a fairly large number in fall at both Pittsburgh and Norfolk. This same pattern exists generally at 1900 LST except that at New York twice as many inversions occur in spring than in winter at that time. At the other three stations the minimum number of inversions occur in spring and summer at 1900 LST. During the nighttime hours, illustrated by the 2200 and 0700 radiosonde observations, the picture changes somewhat. At New York, Pittsburgh, and Washington, the maximum number of inversions at 2200 occur in the fall. Summer was the next most frequent inversion period at this time. The Norfolk figures do not agree with this distribution although the variation in frequency of inversions is fairly small so that these differences are probably not significant. The 0700 LST observations show a maximum frequency in the spring at New York and Pittsburgh, in the fall at Washington, and both in the spring and fall at Norfolk. Considering all four time periods together it is clear that fall and winter conditions are most conducive to the occurrence at low level temperature inversions in eastern United States.

The actual percentage frequencies shown on the table are also significant, ranging from only 1 percent frequency at 1000 LST at New York during the summer and fall up to 68 percent of the time with inversions in the spring at Pittsburgh at 0700 LST. At the four stations listed, inversion conditions existed for nearly one-half of the total number of hours during all seasons of the year at 2200 and 0700. Thus the opportunity for pollution to build up in the atmosphere to significant proportions is certainly present in the Delaware Valley area.

Frequency of Inversions in the Philadelphia Area

Observations of the vertical profile of air temperature in the Philadelphia area are quite limited. From October 1954 to March 1956, a U. S. Army Anti-Aircraft battalion was located in Springfield, Delaware County, about 10 miles west of the center city, Philadelphia area. Almost daily radiosonde observations were taken at this site during this time. Tables 7 and 8 show the frequency of low-level temperature inversions during this particular time. There is no reason to believe that these data are not entirely representative of conditions at the present time over a wide area of the valley.

In order to group the data into manageable categories, a rise of 2°F or greater through the first 600 feet is called a significant inversion, and a rise of 4°F or greater in the first 600 feet is called a marked inversion. Because of gaps in the record, the monthly figures given in tables 7 and 8 are made up in part of 1954, 1955, and 1956 observations. Wind directions at the times of inversions are also included in the tables.

A total of 219 inversions occurred during the period under consideration. Of this number, 116 or 53 percent were marked inversions and the remaining 103 were significant inversions. Figures 19 and 20 show the number of inversions by months by means of bar graphs. The seasonal occurrence of these inversions is significant because of the relationship between inversions and the possibility of air pollution. The four months, June-September, contained 50.7 percent of all inversions and 66.4 percent of the marked inversions. If May is added to these figures we find 61.2 percent and 76.8 percent, respectively, of the significant and marked inversions. July and August are the most critical months with 21.6 and 19.8 percent of the marked inversions occurring in those months respectively.

Table 7

Occurrence of Inversions 2°F or Greater Per 600 Feet Increase in Elevation (By Month and Wind Direction)

Month	Wind Direction 0°	45°	90°	135°	180°	225°	270°	315°	Total Inversions (By Months)	% of Total Inversions (By Months)
January, 1956	1	0	2	0	1	2	2	1	9	4.0
February, 1956	1	1	1	1	0	2	3	3	12	5.5
March, 1956	2	1	1	0	0	0	4	3	11	5.0
April, 1955	0	0	3	2	1	2	2	2	12	5.5
May, 1955	4	2	1	1	2	4	3	6	23	10.5
June, 1955	5	0	2	1	0	3	3	9	23	10.5
July, 1955	4	5	1	1	3	4	8	4	30	13.7
August, 1955	7	2	2	4	4	5	3	3	30	13.7
September, 1955	2	6	6	2	5	4	1	2	28	12.8
October, 1954	1	1	1	2	4	5	3	2	19	8.7
November, 1954	0	3	1	2	0	1	3	0	10	4.6
December 1954	0	0	1	1	0	6	1	3	12	5.5
Total Inversions (By Wind Direction)	27	21	22	17	20	38	36	38	219	
% of Total Inversions (By Wind Direction)	12.3	9.6	10.0	7.8	9.1	17.4	16.4	17.4	100	100

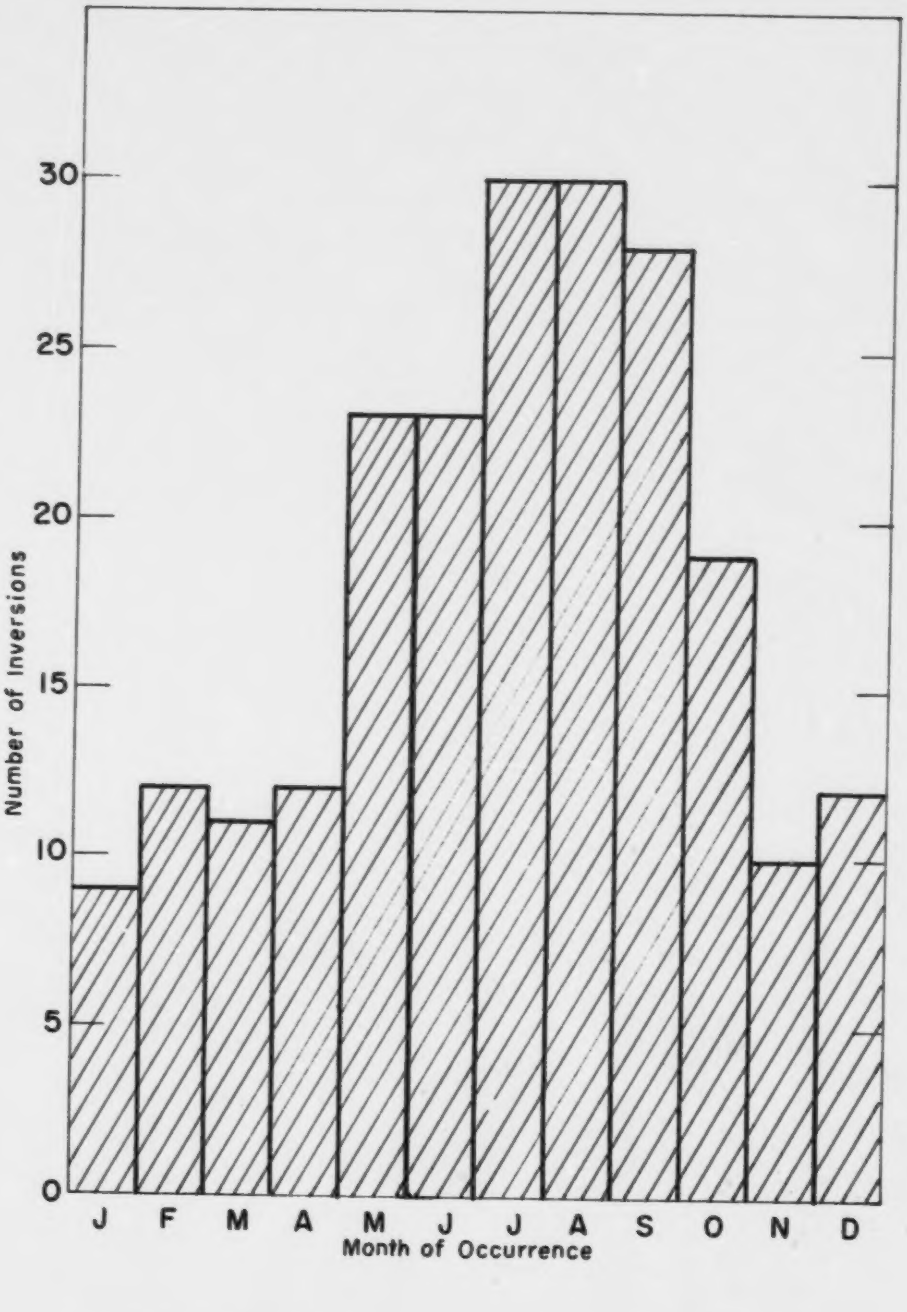
Table 8

Occurrence of Inversions 4°F or Greater Per 600 Feet Increase in Elevation (By Month and Wind Direction)

Month	Wind Direction 0°	45°	90°	135°	180°	225°	270°	315°	Total Inversions (By Months)	% of Total Inversions (By Months)
January 1956	0	0	0	0	0	0	0	0	0	0
February, 1956	1	0	0	1	0	0	1	0	3	2.6
March, 1956	1	0	0	0	0	0	1	1	3	2.6
April, 1955	0	0	1	0	0	0	1	2	4	3.4
May, 1955	2	1	1	0	1	2	3	2	12	10.4
June, 1955	1	0	0	0	0	3	3	6	13	11.2
July, 1955	4	2	1	1	3	3	7	4	25	21.6
August, 1955	3	1	2	4	4	4	3	2	23	19.8
September, 1955	2	3	3	2	3	1	1	1	16	13.8
October, 1954	1	0	0	1	2	3	2	0	9	7.8
November, 1954	0	1	1	0	0	1	1	0	4	3.4
December, 1955	0	0	0	1	0	3	0	0	4	3.4
Total Inversions (By Wind Direction)	15	8	9	10	13	20	23	18	116	
% of Total Inversions (By Wind Direction)	12.9	6.9	7.8	8.6	11.2	17.2	19.8	15.5	100	100

From observations by A. A. Battalion, U. S. Army, located near Philadelphia, Pa.

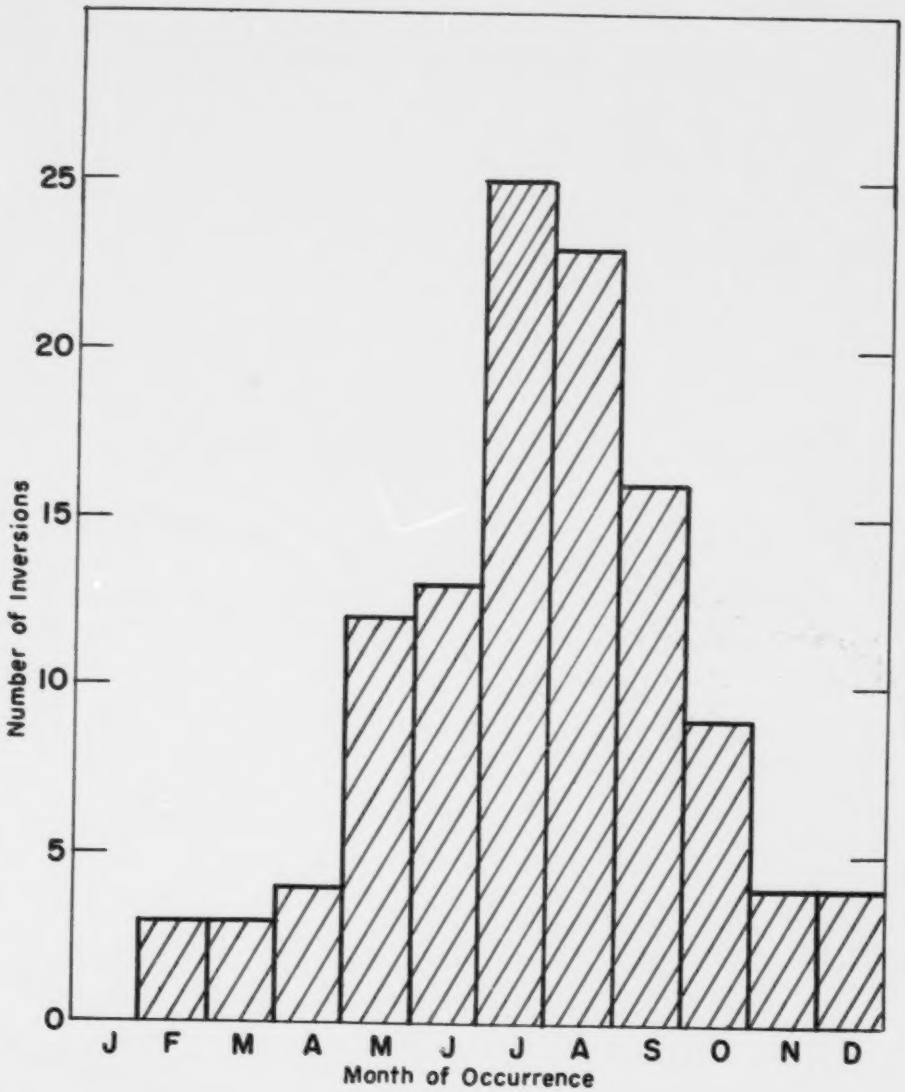
INVERSIONS OF 2°F. OR GREATER PER 600 FEET INCREASE IN ELEVATION - BY MONTHS



From observations taken at a station near Philadelphia, Pa.

Figure 19

INVERSIONS OF 4°F. OR GREATER PER 600 FEET INCREASE IN ELEVATION - BY MONTHS



From observations taken at a station near Philadelphia, Pa.

Figure 20

The tendency for marked inversions to persist for periods of a day or more is of critical significance. Atmospheric stability as a rule occurs most frequently and persists for the longest times in summer and early fall. In the summer, however, heating by the sun tends to destroy all but the most persistent inversion. It should be recognized, of course, that stability which accompanies temperature inversions occurs in all seasons.

Table 9, although based on data for a limited period, shows that there is a tendency for inversions to last longer in the middle of the summer and in the fall than at other times of the year. Of the marked inversions which persisted for six days or longer, all but two occurred after mid-July and the entire number fell within the June-September period. Furthermore, while January was the only month when marked inversions were not recorded, it was uncommon for this condition to endure for more than one day at any time during the months of October through April.

Table 9

Persistence of Marked Inversions 4°F or Greater
Per 600 Feet Increase in Elevation

	Duration of Inversion (Days)									
Month	1	2	3	4	5	6	7	8	Total Occurrences	Total Days with Inversions
January, 1956	0	0	0	0	0	0	0	0	0	0
February, 1956	1	1	0	0	0	0	0	0	2	3
March, 1956	3	0	0	0	0	0	0	0	3	3
April, 1955	4	0	0	0	0	0	0	0	4	4
May, 1955	2	2	2	0	0	0	0	0	6	12
June, 1955	0	3	0	0	0	0	1	0	4	13
July, 1955	2	1	0	0	0	1	1	1	6	25
August, 1955	0	1	0	0	0	1	1	1	4	23
September, 1955	3	1	1	0	0	0	0	1	6	16
October, 1954	4	0	0	0	1	0	0	0	5	9
November, 1954	4	0	0	0	0	0	0	0	4	4
December, 1954	1	0	1	0	0	0	0	0	2	4
Total Occurrences	24	9	4	0	1	2	3	3	46	116

From observations by A. A. Battalion, U. S. Army, located near Philadelphia, Pa.

Mean Mixing Depths as an Indicator of Pollution Potential

The concept of the mixing depth has been developed in an attempt to obtain another indication of the potential mixing of the atmosphere due to afternoon heating from the surface. The maximum mixing depth (MMD) has been defined as the depth of atmosphere through which vigorous mixing could occur as a result of heating of the air layer by conduction-convection during the afternoon (Holzworth, 1964). It is obtained by taking the maximum afternoon temperature at the surface and following the dry adiabatic lapse rate from this temperature to its intersection with the most recently observed actual temperature profile at the place in question. It is considered that below this intersection afternoon heating will result in vigorous mixing of the air and the establishment of a dry adiabatic lapse rate. Above the intersection, a more stable lapse rate will continue to exist, and this will put a general upper limit on the extent of dispersion of pollutants through the lower atmosphere. The greater the height of the intersection (or the greater the MMD), the greater will be the atmosphere's opportunity to mix and disperse pollutants.

Holzworth (1964) cautions

> "In order to estimate MMD's it is necessary to make some general assumptions, based upon meteorological experience, about the manner in which the vertical temperature structure of the lower atmosphere varies diurnally. Briefly, these are that nocturnal radiational cooling of the ground and heat loss from the air to the cool ground result in stable lapse rates at night; and that during daytime, absorption of solar radiation by the ground and heat conduction to the air in contact with the warm ground result in unstable lapse rates and vertical motions (mixing) that ultimately produce a mixed dry adiabatic layer. Neglecting as insignificant other factors (advection, subsidence, etc.) that could cause changes in the vertical temperature profile between its time of observation and that of the surface maximum temperature, it is assumed that the MMD depends upon the vertical temperature structure and the surface maximum temperature. This last assumption must be further conditioned by the fact that effects of vertical wind shear and mechanical turbulence in augmenting or diminishing vertical mixing have been neglected. In some cases these factors may be important. . . ." (p. 235)

Holzworth investigated the seasonal and geographic differences in vertical mixing during the daytime when such mixing is usually at a maximum. Because of the availability of the data, Holzworth used monthly average radiosonde observations and average maximum surface temperatures to compute monthly mean maximum mixing depths. Table 10 shows the results of Holzworth's computations for four stations just outside the Delaware Valley area based on approximately 10 years of radiosonde observations. While Nantucket has a much lower mean maximum mixing depth than the other three stations because of maritime considerations, there is a reasonable seasonal variation in mean mixing depth at the other three stations. Lowest mean mixing depths are found during the winter months of December, January, and February. Mixing depths are greater in the spring and fall and usually reach their maximum in the summer time.

On the basis of other considerations, Holzworth felt that mean mixing depths greater than 1500 meters were essentially unlimited, and that the lower the mixing depth the greater the possibility of air pollution, other things being equal. He concluded:

Table 10

Computed Monthly Mean Maximum Mixing Depths (in meters) for Selected East Coast Stations[1]

Station	J	F	M	A	M	J	J	A	S	O	N	D
Buffalo, N.Y.	480	530	780	810	1070	1180	1440	1360	1190	530	700	510
Nantucket, Mass.	360	330	470	340	350	360	350	430	440	250	350	490
Pittsburgh, Pa.	340	590	1040	1150	1510	1370	1450	1370	1240	630	730	410
Washington, D.C.	400	570	1000	930	1120	1310	1180	990	980	570	680	480

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[1] Adapted from Holzworth, G. C., 1964, Table 1, p. 237.

> "Along the middle Atlantic and New England coasts mean MMD's are relatively shallow throughout the year, and are particularly low during November through February when they are mostly less than 500 m. This is partly because of the cool Labrador current. On a yearly basis the station with the lowest mean MMD's is Nantucket, where the monthly means range between 250 and 590 m. Although mean MMD's are shallow along the middle Atlantic and New England coasts, other factors, such as relatively moderate wind speeds and frequent storm passages, tend to offset the shallow MMD's in affecting the local accumulation of air pollutants." (p. 242)

The figures for maximum mixing depth for the four stations in the northeastern part of the country are generally below the nationwide average. Based on data from all 45 stations investigated by Holzworth, the mean January mixing depth is 497 meters for the country as a whole. Only Buffalo in the eastern United States approximates this mean value. In July, the mean figure for the United States is 1709 meters, several hundred meters greater than the Pittsburgh and Buffalo observations and 1500 meters above the value given for Nantucket. Thus on the basis of mean mixing depth, eastern United States and the Delaware Valley area would seem to have the potential, at least, for significant air pollution episodes.

Detailed Study of Mean Mixing Depths in the Delaware Valley

To carry Holzworth's general study of mean maximum mixing depths further, the frequency of episodes in which mixing depths of different thicknesses were found to occur at New York, Pittsburgh, and Washington, were obtained through the courtesy of the National Weather Records Center, Environmental Data Service, Asheville, N.C. They have provided a summary, by months and by seasons of the year, of the number of consecutive observation periods during which different combinations of mean wind speed and thicknesses of mixing depth have occurred. The available record for Washington covered 1961-64, for Pittsburgh, 1960-64, and New York, 1960-64.

Tables 11a-c have been adapted from the Environmental Data Service summary to show the more salient features of their detailed tabulation. The summaries in tables 11a-c give the number of times that a mixing depth equal to or less than 250, 500, 1000, or 2000 m existed for various time periods (wind speed $\leq$8 mps) by months for the three stations. In addition, the total number of mixing depth episodes, including all those that existed for less than one day, is given in the right-hand column. Because of the way in which the table is arranged, each succeeding table includes the cases in the preceding tables and, of course, each column of each table includes all the results in the columns farther to the right (except the total, all cases, column). Thus, the maximum numbers will always be found in the left-hand column of the bottom (mixing depth $\leq$2000 m) table for each station since episodes that existed for longer time periods and with smaller mixing depths will also be included in this column.

Consideration of the data in table 11 reveals a very interesting pattern which can also be expected to occur over the Delaware Valley area. The most limiting conditions from a pollution point of view would be the occurrence of long consecutive periods with low mixing depths. Very few examples of mixing depths less than 250 or 500 meters lasting at least one day were found at the three nearby stations. Those that did occur were found primarily in January and December (a total of 9 cases at Pittsburgh and 11 cases at Washington). At New York, October and November were the favored months with 15 cases. Very low mixing depths that lasted for at least 24 hours, therefore, were a late fall or wintertime phenomena, and this might be anticipated on the basis of the computations used. Surface maximum temperatures would not be great in the winter while actual lapse rates would be fairly vertical or stable. Thus, the intersection of the dry adiabat from the surface maximum temperature with the actual lapse rate would occur at a low elevation.

The maximum number of total occurrences of such low mixing depth episodes (mostly existing for less than one day) does not follow this pattern at all. Instead, a summer or early fall maximum is found as follows: Pittsburgh 106 in July, 103 in September; Washington 92 in October, 80 in June; New York 91 in October, 70 in May. Winds are lighter in the summer than in the winter so there are more time periods with winds less than 8 mps in summer. The summer maximum of low wind - mixing depth episodes is probably related to this occurrence of more periods of lighter winds in summer rather than to any actual increase in total number of low mixing depth episodes.

As the mixing depth increases to 1000 and 2000 meters, the period of maximum frequency for both longer consecutive time periods and for all time periods shifts to the late summer. While two episodes lasting for at least 10 consecutive days with mixing depths less than 2000 m did exist in November at Pittsburgh, and one episode at New York and Washington lasting for at least 12 days existed in October, the maximum of 4-, 5-, and 6-day periods of such mixing depths is found in September or October. August has the greatest number of mixing depths $\leq$2000 m existing for one or more days at all three stations as well as the greatest number of such mixing depths existing for all time periods (found on at least one radiosonde ascent) at Pittsburgh and New York. October has the greatest number of such mixing depths at Washington although August is not far behind.

Table 11a
Monthly Distribution of Periods with Various Maximum Mixing Depths at Pittsburgh, Pennsylvania, 1960-64

	Duration (days) equal to or greater than 1	2	3	4	5	6	7	8	9	10	12	Total all cases
Mixing Depth ≤250 m: Avg. wind speed ≤8 mps.												
J	2											32
F												38
M												35
A												54
M												59
J												63
J												79
A												73
S												77
O												84
N												44
D	1											35
Mixing Depth ≤500 m: Avg. wind speed ≤8 mps.												
J	5											50
F	2											50
M	1											51
A												68
M	1											82
J												93
J												106
A												101
S	1											103
O												98
N	2											62
D	4	1	1									52
Mixing Depth ≤1000 m: Avg. wind speed ≤8 mps.												
J	12	5	3	1								94
F	9	2	1	1								82
M	5											78
A	3											84
M	2											103
J	1											111
J	2											124
A	3											123
S	8	1										129
O	9											131
N	11	4	3	1	1	1	1	1	1			104
D	7	1	1									82
Mixing Depth ≤2000 m: Avg. wind speed ≤8 mps.												
J	14	6	3	1								103
F	13	3	1	1								92
M	14	5	1	1								113
A	16	2	1									116
M	20	10	2									148
J	22	14	3	1	1							173
J	29	14	7	3								189
A	32	19	9	3	2	1	1					216
S	24	18	12	9	5	4	2	2	2			211
O	28	15	10	4	4	3	3	2	1			204
N	17	8	5	3	2	2	2	2	2	2		148
D	9	3	2	1								94

Table 11b

b) Washington, D. C., 1961-64

	Duration (days) equal to or greater than											Total all
	1	2	3	4	5	6	7	8	9	10	12	cases
Mixing Depth ≤250 m: Avg. wind speed ≤8 mps.												
J	2											59
F												36
M	1											48
A	1											44
M												50
J												52
J												49
A												47
S												61
O	1											79
N												51
D	1											44
Mixing Depth ≤500 m: Avg. wind speed ≤8 mps.												
J	6	1										75
F	1											48
M	1											59
A	1											54
M	1											72
J												80
J												77
A												69
S	1											79
O	3											92
N	2											65
D	5											70
Mixing Depth ≤1000 m: Avg. wind speed ≤8 mps.												
J	11	5	1	1								117
F	8	1										83
M	5	1										84
A	2											74
M	3	1										99
J	2	2										97
J	2											107
A	2	1										107
S	5											101
O	13	4	1									118
N	12	3										101
D	13	5	2	1	1	1	1	1				103
Mixing Depth ≤2000 m: Avg. wind speed ≤8 mps.												
J	23	10	2	1	1							141
F	14	4	1									101
M	18	3										117
A	7	1	1	1								89
M	18	8	3	2	2	1						142
J	18	6	4	2	1	1						141
J	20	6	2	2	1	1	1	1	1			151
A	28	9	5	3	1							159
S	20	13	9	5	3	1	1	1				161
O	17	12	9	5	4	3	3	3	2	1	1	176
N	18	10	4	1	1							134
D	16	8	7	4	1	1	1	1				128

Table 11c

c) New York, N. Y., 1960-64

	Duration (days) equal to or greater than											Total all cases
	1	2	3	4	5	6	7	8	9	10	12	
Mixing Depth ≷250 m: Avg. wind speed ≷8 mps.												
J	1											25
F												14
M	1											22
A	2											26
M												33
J												25
J												13
A												11
S												18
O												42
N	1											30
D	1											15
Mixing Depth ≷500 m: Avg. wind speed ≷8 mps.												
J	2											48
F	4											32
M	2											42
A	5											53
M	3											70
J												68
J	1											58
A												48
S												50
O	9	4	2									91
N	6	1										57
D	3											36
Mixing Depth ≷1000 m: Avg. wind speed ≷8 mps.												
J	7	3										96
F	12	3	1	1								75
M	4	1										76
A	8											73
M	14	2	1									116
J	7											103
J	9	2										121
A	7											102
S	9	1	1									110
O	18	7	4	1	1							133
N	18	4	1									110
D	9	4	3	1	1							89
Mixing Depth ≷2000 m: Avg. wind speed ≷8 mps.												
J	13	5	3	1								129
F	13	3	1	1								95
M	9	2										107
A	13	2										104
M	19	9	4	1								149
J	26	7	1	1	1							156
J	25	9	4	3	2	1						181
A	27	10	6	4	3	1						191
S	21	13	7	5	2	2	2	1	1	1		179
O	21	14	8	4	4	2	2	1	1	1	1	183
N	20	8	5	3	2	1						140
D	13	5	4	1	1							108

Holzworth's study which found the lowest mean maximum mixing depths in January in eastern United States does not necessarily contradict these results since his figures were based on an average maximum surface temperature and an average monthly lapse rate without regard to mean wind speed through the mixing depth layer. The present figures of low mixing depths agree well with the figures on the frequencies of inversions and reaffirm our earlier conclusion that inversions or low mean mixing depths are not the only conditions leading to atmospheric pollution. Other meteorological conditions such as general atmospheric circulation and the occurrence of stagnant, stable high pressure areas and non-meteorological conditions such as increased combustion products leading to increased pollution opportunities in winter will also influence the distribution of pollution episodes.

The figures given in table 11 have been summed by season in table 12. This table emphasizes that essentially all the low mean maximum mixing depths are found in the winter season while the late summer and fall experience the greatest number of occurrences of mixing depths of all durations and thicknesses. This pattern is not as clearly shown at New York as at Washington and Pittsburgh and is undoubtedly influenced by the proximity of the ocean. It is felt that conditions in the Delaware Valley area will more closely approximate Washington and Pittsburgh conditions than those at New York.

The mean mixing depth episodes have been summed a second way in order to provide additional information on the pattern of their seasonal distribution. First, occurrences with and without precipitation were separated since the physical processes followed by rising saturated and unsaturated air parcels are different. Then the morning and afternoon radiosonde ascents were tabulated separately so that it is not possible to determine the extent of mixing depth episodes, but only the frequency of occurrence with different mean wind speeds through the mixing depth.

The results are included in table 13 where the upper table shows the early morning situation and the bottom table the afternoon condition. The early morning tabulation is entirely similar in distribution to those shown in tables 11 and 12. There is a seasonal change in number of mixing depth episodes with the largest number of occurrences in summer (June through October) and the minimum number in winter (December through February). The number of episodes (without regard to wind velocity) which occurred with precipitation were also tabulated and the pattern is entirely reversed. Here the maximum number of precipitation occurrences with mixing depths less than 500 m occurred in winter (December through March) and the minimum number of such episodes came in August, September and October. However, there were many more mixing depth episodes without precipitation so that the seasonal distribution of the non-precipitation episodes predominates.

The distribution of afternoon mixing depth episodes is also reversed from the distribution of morning episodes without precipitation. Using the afternoon radiosonde ascent, it has been found that the maximum number of mixing depth episodes (<500 m) either with or without precipitation occurs in the winter season (December, January, and February) while the minimum occurrence is found in summer (June, July, and August). The total number of mixing depth episodes is much less as would be expected in the afternoon than in the early morning. This is related to the diurnal shifts in the actual temperature profile from early morning to afternoon.

Table 12

Seasonal Summary of Periods with Various Maximum Mixing Depths
(Wind Velocity through Mixing Depth ≤8 mps)

Pittsburgh, Pa., 1960-64

Avg. wind speed ≤8 mps.

Mix Depth	Duration (days) equal to or greater than 1	2	3	4	5	6	7	8	9	10	12	Total all cases
December, January, February												
≤ 250 m	3											105
≤ 500 m	11	1	1									152
≤1000 m	28	8	5	2								258
≤2000 m	36	12	6	3								289
March, April, May												
≤ 250 m												148
≤ 500 m	2											201
≤1000 m	10											265
≤2000 m	50	17	4	1								377
June, July, August												
≤ 250 m												215
≤ 500 m												300
≤1000 m	6											358
≤2000 m	83	47	19	7	3	1	1					578
September, October, November												
≤ 250 m												205
≤ 500 m	3											263
≤1000 m	28	5	3	1	1	1	1	1	1			364
≤2000 m	69	41	27	16	11	9	7	6	5	2		563

Washington, D. C., 1961-64

Avg. wind speed ≤8 mps.

Mix Depth	Duration (days) equal to or greater than 1	2	3	4	5	6	7	8	9	10	12	Total all cases
December, January, February												
≤ 250 m	3											139
≤ 500 m	12	1										193
≤1000 m	32	11	3	2	1	1	1	1				303
≤2000 m	53	22	10	5	2	1	1	1				370
March, April, May												
≤ 250 m	2											142
≤ 500 m	3											185
≤1000 m	10	2										257
≤2000 m	43	12	4	3	2	1						348
June, July, August												
≤ 250 m												148
≤ 500 m												226
≤1000 m	6	3										311
≤2000 m	66	21	11	7	3	2	1	1	1			461
September, October, November												
≤ 250 m	1											191
≤ 500 m	6											236
≤1000 m	30	7	1									320
≤2000 m	55	35	22	11	8	4	4	4	2	1	1	471

Table 12
(continued)

New York, N. Y., 1960-64

Average wind speed ≤8 mps.

Mix Depth	Duration (days) equal to or greater than 1	2	3	4	5	6	7	8	9	10	12	Total all cases
December, January, February												
≤ 250 m	2											54
≤ 500 m	9											116
≤1000 m	28	10	4	2	1							260
≤2000 m	39	13	8	3	1							332
March, April, May												
≤ 250 m	3											81
≤ 500 m	10											165
≤1000 m	26	3	1									265
≤2000 m	41	13	4	1								360
June, July, August												
≤ 250 m												49
≤ 500 m	1											174
≤1000 m	23	2										326
≤2000 m	78	26	11	8	6	2						528
September, October, November												
≤ 250 m	1											90
≤ 500 m	15	5	2									198
≤1000 m	45	12	6	1	1							353
≤2000 m	62	35	20	12	8	5	4	2	2	2	1	502

Table 13

Frequency of Wind Speeds and Morning and Afternoon Mixing Depths Less than 500 m for Periods With and Without Precipitation Pittsburgh, Pennsylvania, Washington, D. C. and New York, New York

Pittsburgh, Pennsylvania, 1960-64

	Wind Speed (mps) 1	2	3	4	5	6	7	8	Others	Total No. P	Total P	Total
Time - Morning												
J	7	5	8	7	4	4	3	2	1	41	22	63
F	8	13	10	7	3	1	3	4	0	49	16	65
M	10	6	10	4	8	9	2	3	0	52	15	67
A	19	8	10	14	7	6	3	3	0	70	12	82
M	18	17	13	10	7	4	11	2	1	83	10	93
J	37	12	13	11	7	8	5	1	1	95	9	104
J	39	23	21	12	4	7	0	1	0	107	6	113
A	33	16	27	11	10	1	2	1	0	101	4	105
S	33	21	20	10	10	4	2	0	1	101	6	107
O	45	15	18	6	7	5	1	0	2	99	3	102
N	15	6	15	6	2	7	2	3	2	58	8	64
D	8	5	10	9	3	2	2	1	1	41	23	64
Time - Afternoon												
J	1	0	2	1	3	2	3	1	2	15	29	44
F	0	1	1	0	0	1	2	2	0	7	30	37
M	0	0	0	1	0	0	1	0	1	3	22	25
A	0	0	0	0	1	0	0	0	1	2	13	15
M	0	0	0	0	0	1	1	0	0	2	10	12
J	0	0	0	0	0	0	0	0	0	0	5	5
J	0	0	0	0	0	0	0	0	0	0	5	5
A	0	0	0	1	0	0	0	0	0	1	2	3
S	0	1	1	1	0	0	0	0	0	3	9	12
O	0	0	1	0	0	0	0	1	0	2	9	11
N	0	0	2	1	0	1	5	2	0	11	18	29
D	1	1	1	3	4	0	3	0	0	13	39	52

Table 13
(Continued)

Washington, D. C., 1961-64

Time - Morning	Wind Speed (mps) 1	2	3	4	5	6	7	8	Others	Total No. P	Total P	Total
J	19	8	13	8	1	3	4	3	0	59	15	74
F	12	7	8	8	2	2	2	1	1	43	20	63
M	11	10	16	6	5	3	6	1	0	58	12	70
A	11	9	13	9	3	5	2	1	0	53	6	59
M	21	13	13	11	3	6	3	1	0	71	5	76
J	29	12	14	10	7	4	3	2	0	81	8	89
J	20	22	15	9	4	5	2	0	0	77	7	84
A	22	13	17	4	8	3	2	0	0	69	7	76
S	21	22	15	8	5	2	4	2	0	79	5	84
O	32	23	19	5	2	3	3	0	0	87	5	92
N	25	12	10	4	3	2	3	4	0	63	7	70
D	8	17	10	10	2	3	1	1	1	53	10	63
Time - Afternoon												
J	1	3	4	1	4	3	3	2	2	23	13	36
F	1	0	2	2	1	1	0	2	1	10	25	35
M	0	1	0	0	0	1	0	1	1	4	11	15
A	0	0	0	0	1	0	1	0	0	2	7	9
M	0	0	0	0	2	0	0	0	0	2	5	7
J	0	0	0	0	0	1	0	0	0	1	4	5
J	0	0	0	0	0	0	0	0	0	0	2	2
A	0	0	0	0	0	0	0	0	0	0	2	2
S	0	0	0	0	1	1	0	0	0	2	7	9
O	0	0	0	0	2	3	0	0	0	5	7	12
N	0	2	0	1	0	1	2	2	2	10	10	20
D	0	2	4	3	2	3	5	2	0	21	15	36

Table 13
(Continued)

New York, N. Y., 1960-64

	Wind Speed (mps)									Total	Total	Total
	1	2	3	4	5	6	7	8	Others	No. P	P	
Time - Morning												
J	0	4	9	5	1	7	7	2	2	37	16	53
F	0	3	9	2	0	5	6	1	3	29	15	44
M	0	5	8	7	1	5	5	3	0	34	19	53
A	0	2	6	9	8	6	8	0	0	39	18	57
M	0	2	14	18	10	12	5	5	0	66	10	76
J	0	5	13	14	14	7	7	5	0	65	11	76
J	0	5	13	9	9	9	7	0	0	52	3	55
A	1	5	10	8	6	7	9	2	0	48	4	52
S	1	6	13	8	6	5	8	1	2	50	3	53
O	1	9	22	7	14	7	9	0	2	71	3	74
N	0	7	11	9	5	3	4	6	3	48	6	54
D	0	2	6	5	4	2	4	1	1	25	13	38
Time - Afternoon												
J	0	0	0	2	6	2	5	4	4	23	25	48
F	0	0	0	2	3	1	1	1	3	11	24	35
M	0	0	1	2	3	1	4	2	6	19	19	38
A	0	0	1	1	4	0	8	4	3	21	16	37
M	0	0	0	0	2	1	6	1	3	13	16	29
J	0	0	0	0	5	0	3	3	0	11	15	26
J	0	0	0	0	2	2	2	1	0	7	7	14
A	0	0	0	1	0	0	1	1	0	3	7	10
S	0	0	0	2	0	1	0	1	0	4	7	11
O	0	2	0	2	6	4	8	2	2	26	8	34
N	0	0	2	4	2	1	9	2	4	24	11	35
D	0	1	1	3	2	3	3	2	6	21	20	41

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While the table does not show duration of low mixing depth occurrences, it is clear that many of those situations during which mixing depths of less than 500 m existed in the afternoon must also have had fairly low mixing depths at the time of the morning radiosonde ascent as well. It is, therefore, the afternoon periods that determine the existence of extensive periods of low mixing depth and of possibly high atmospheric pollution. The afternoon mixing depth is probably more closely related to air quality than any other single meteorologic factor.

The MMD by itself or even combined with relevant wind data is not an overall index of potential for air pollution. It still has value, however, as a forecasting tool because of the need to have low mean mixing depths and low wind speeds along with other meteorological and non-meteorological conditions before serious pollution conditions can develop.

In a very recent study, Miller (1967) has introduced a method of forecasting afternoon mixing depths and wind speeds for use in preparing special forecasts of possible pollution conditions. He estimates the vertical extent of atmospheric mixing during the afternoon by assuming that the afternoon mixing depth is "dependent upon the observed difference between the maximum afternoon surface temperature and the mean virtual temperature of the standard atmospheric layer containing the top of the mixing depth. Transport wind speed is assumed to be a function of the wind speed at the level nearest the center of the mixing depth." (p. 35). Parabolic regression equations between the parameters of interest and selected independent variables were obtained and used to provide forecasting guides. Sample forecasts made with the method during April and May 1966 were useful enough so that the method is being incorporated into the National Air Pollution Forecast program.

Conclusions

Temperature inversions in the Delaware Valley area are more frequent in late summer and fall. At the same time, low mean mixing depths are also more frequent in late fall and winter. Thus, on the basis of atmospheric stability conditions, it would appear that the fall of the year is the time when meteorologic conditions are most favorable for high pollution episodes; yet the record which is developed in the next chapter shows that winter is the period that actually experiences high pollution episodes most frequently.

Two factors seem to be responsible for this. First, the duration of the limiting meteorological condition, whether it be low wind velocities, temperature inversions, or low mixing depth is probably the most important contributor to episodes of high pollution. Thus, while the frequency of some of these events may be greater in late summer or fall, it is only in the winter that conditions exist which will result in the longest duration of some of these limiting events.

Second, severe atmospheric pollution also requires the sources of contamination. While these are present in all seasons, it appears that the winter season, with its increased heating needs, provides additional quantities of pollutants to be dispersed in the air. Thus, even though the meteorologic opportunities for pollution episodes may be less frequent in winter, the non-meteorologic conditions contributing to pollution (abundance of sources of pollution) favor the winter period. This, combined with the longer duration of such factors as very low mixing depths, can result in more serious wintertime pollution episodes.

CHAPTER V. AIR QUALITY IN THE DELAWARE VALLEY

Located, as it is, without defined topographic features to restrict or channel air flow, with industries and population centers fairly well dispersed throughout the 11-county area, and in an area of variable wind direction, one would expect that air quality in the Delaware Valley area would be reasonably uniform both areally and with time through the year, and that total concentrations of pollutants would be somewhat above the national average. Higher values of pollution concentration would be expected in the highly industrialized areas with above average values in the more rural areas of the valley.

For the year 1965, a fairly large number of air quality sampling stations were operating in the Delaware Valley area. The list below includes all sampling stations that we have been able to locate and from which we have been able to obtain records for 1965. These sampling sites are also located on the geographical location map of figure 5.

Available Air Quality Sampling Sites, Delaware Valley, 1965

Suspended particulates (selected days)

Newark, Delaware
Wilmington, Delaware
Glassboro, New Jersey
Hamilton, New Jersey
Marlton, New Jersey
Pemberton, New Jersey
Princeton, New Jersey

Eagleville, Pennsylvania
Embreeville, Pennsylvania
Philadelphia, Pennsylvania
Pipersville, Pennsylvania
Sanatoga, Pennsylvania
Warminster, Pennsylvania
West Chester, Pennsylvania

Just outside area

Bridgeton, New Jersey
Jutland, New Jersey
Allentown, Pennsylvania
Bethlehem, Pennsylvania
Lancaster, Pennsylvania
Reading, Pennsylvania

Continuous air monitoring program (CAMP) data

Philadelphia, Pennsylvania	Nitrogen Dioxide (hourly values) Sulfur Dioxide (hourly values)

City of Philadelphia samplers

HVAS (daily average suspended particulates)
AISI samplers (daily average soiling index)
    3200 Frankford Avenue
    1501 E. Lycoming Street
    500 S. Broad Street

Other factors of air quality were sampled daily at the CAMP, Philadelphia station and randomly at some of the suspended particulate stations during 1965, and other air quality sampling stations were operative in other years. The list above for 1965, however, is indicative of the type and extent of the air quality sampling in the Delaware Valley area.

General Air Quality Relationships

In 1966, the Air Quality Section of the R. A. Taft Sanitary Engineering Center, Cincinnati, published a fairly comprehensive summary of the available air quality data from the National Air Sampling Networks and contributing state and local networks which provides a good picture of the air quality in the Delaware Valley area and its relation to the rest of the country. The following four tables and accompanying discussion have been derived from this useful data summary.

Table 14 compares the average concentrations of particular pollutants for six major cities in various parts of the country based only on 1965 data.

Table 14

Summary of Average Concentrations of Particular Pollutants for Selected Cities, 1965 (ppm)

Carbon Monoxide	
Chicago	17.1
Philadelphia	8.1
Denver	7.2
St. Louis	6.5
Cincinnati	4.0
Washington	3.7

Sulfur Dioxide	
Chicago	.130
Philadelphia	.085
St. Louis	.047
Washington	.046
Cincinnati	.030
Denver	.021

Nitric Oxide	
Chicago	.096
Philadelphia	.048
Denver	.033
Washington	.033
Cincinnati	.031
St. Louis	.026

Total Hydrocarbons	
St. Louis	2.9
Cincinnati	2.8
Chicago	2.7
Denver	2.5
Philadelphia	2.2
Washington	2.1

Nitrogen Dioxide	
Chicago	.043
Philadelphia	.036
Denver	.036
Cincinnati	.035
Washington	.034
St. Louis	.026

Total Oxidants	
Cincinnati	.033
Denver	.033
St. Louis	.031
Washington	.028
Philadelphia	.026
Chicago	.026

In each case the cities have been listed in decreasing order of concentration for the particular pollutant. The table shows that Chicago, Philadelphia, and Denver rank 1, 2, 3 in terms of carbon monoxide, nitric oxide, and nitrogen dioxide concentration based on 1965 data. Chicago and Philadelphia are still first and second in terms of sulfur dioxide although Denver has dropped to sixth. In terms of total hydrocarbons and total oxidants Philadelphia is fifth on the list of six major cities. It must be pointed out that Los Angeles, New York, Boston and several other major cities possibly having as high or higher values in certain of these pollutants are not included in the list. There is no question, however, that Philadelphia ranks well up with the other cities in seriousness of its air pollution problem.

Table 15 based on data from all available stations in the United States, separated into urban and non-urban locations, gives the average concentrations for various types of pollution. The very significant difference resulting from station location is immediately apparent. Table 16 is a list of all observing stations having average concentrations of suspended particulates (50 percent frequency distribution) above 150 μg/m^3 during 1965 along with a list of the average suspended particulate concentration at all available Delaware Valley stations for comparison purposes. Philadelphia is the only Delaware Valley station with above 150 μg/m^3 suspended particulate concentration on the basis of the 50 percent frequency distribution, and only Philadelphia, Bethlehem, and Wilmington have average values above the nationwide average for urban stations (table 15). The remaining Delaware Valley stations (some of which might be classed as non-urban) are all above the average non-urban concentration as given in table 15. The relatively high values for all of these stations, many located in small towns, and the rather small variation from Trenton to Pipersville and Jutland, is indicative of the significant level of pollution over the entire Delaware Valley area, and the widespread dispersal of industry and population, and hence sources of pollution, over the whole valley area.

Table 15

Summary of Average and Maximum Concentrations of Various Types of Pollution

	No. of Stations	Average Concentration μg/m^3
Urban Stations		
Suspended Particulates	291	105
Benzene-Soluble Organics	218	6.8
Sulfur Dioxide	36	62
Nitrogen Dioxide	31	95
Non-urban Stations		
Suspended Particulates	32	37
Benzene-Soluble Organics	28	1.2

Table 16

Concentration of Suspended Particulates at Selected Cities 1965 - 50 Percent on Frequency Distribution

All Stations Above 150 μg/m^3	
Stuebenville, Ohio	258 μg/m^3
East Chicago, Illinois	200
East St. Louis, Missouri	190
Weirton, W. Virginia	189
Granite City, Illinois	188
Philadelphia, Pennsylvania	186
New York, New York	172
Bakersfield, California	171
Birmingham, Alabama	165
Indianapolis, Indiana	165
El Paso, Texas	165
Reno, Nevada	165
San Bernardino, California	158
Johnstown, Pennsylvania	157
Trenton, Michigan	154
Los Angeles, California	152
Lubbock, Texas	152

Delaware Valley Stations	
Philadelphia, Pennsylvania	186 μg/m^3
Bethlehem, Pennsylvania	137
Wilmington, Delaware	122
Trenton, New Jersey	99
Sanatoga, Pennsylvania	99
Princeton, New Jersey	85
Newark, Delaware	77
Allentown, Pennsylvania	71
Glassboro, New Jersey	68
West Chester, Pennsylvania	66
Bridgeton, New Jersey	62
Pemberton, New Jersey	61
Embreeville, Pennsylvania	61
Pipersville, Pennsylvania	60
Jutland, New Jersey	51

Based on an analysis of all urban stations, the Public Health Service report separated the data into five equal groups and gave ranges of average suspended particulate concentration for each group (table 17). Again referring to table 16, it can be seen that only Philadelphia and Bethlehem of the Delaware Valley stations that are sampled are in the top fifth and Wilmington is the only local station in the next highest fifth. Trenton, N. J. and Sanatoga, Pa. are in the middle fifth of sampled urban areas while Princeton, N. J. and Newark, Del. are in the next to lowest fifth. All other sampling sites, including such places as Allentown, Pa. and Bridgeton, N. J., are well up in the lowest fifth of the urban-area categories.

Table 17

Ranges of Suspended Particulate Concentrations Dividing List of 300 Cities into Five Equal Groups

Highest fifth	136-245 μg/m^3
Next highest	106-134
Middle fifth	93-105
Next lowest	77- 92
Lowest fifth	38- 76

The Taft report also provides average figures of suspended particulates by states for 1965. While the national average is 87 μg/m³, the three Delaware Valley states of interest are all above the national average. West Virginia and Nevada have the highest average concentration at 151 μg/m³ followed by Missouri at 139 and Colorado at 132. Delaware with an average value of 110 μg/m³ is 10th on the list and Pennsylvania at 103 μg/m³ is 14th. New Jersey is just above the national average of 88 μg/m³.

The Philadelphia continuous air monitoring program (CAMP) station provides a tremendous amount of detailed daily and hourly (and shorter period) data on air quality. Table 18 sums up the average monthly concentrations, and the maximum 24-hour, and 1-hour concentrations of carbon monoxide, nitric oxide, nitrogen dioxide, sulfur dioxide, total hydrocarbons, and total oxidants, at the Philadelphia CAMP station for 1965. In certain cases, monthly data from 1964 were substituted since too many records for 1965 were missing.

Carbon monoxide, nitric oxide, and sulfur dioxide show a similar pattern of distribution through the year with high values in the fall and winter months and low values in the spring and summer. October and February had the highest values of carbon monoxide while December and January had the highest values of nitric oxide and sulfur dioxide.

Nitrogen dioxide, total hydrocarbons, and total oxidants are distributed in the reverse fashion with higher values in the spring and summer months and lower values in the fall and winter season of the year based on 1965 data. The period May through September experiences high values of these three types of pollutants while lowest values are found in November (nitrogen dioxide), January (total hydrocarbons), and February (total oxidants).

The general pattern of air quality in the Delaware Valley based on average data and data for the year 1965 is one of serious but not extreme conditions in any of the pollutants. Philadelphia itself ranks well up with other major cities in experiencing all types of air pollutants. Other industrial complexes in the valley area rank well below Philadelphia in all pollution indices. There is, in general, a moderate to fairly high level of pollution over the whole area as a result of the concentration of people and industry in the valley area. The potential for very serious pollution exists, and it is probably only because of the relatively favorable meteorological and topographical conditions that more serious pollution episodes do not develop.

Geographic Distribution of Suspended Particulate Concentration

Through the courtesy of Mr. Elbert Tabor, Chief, National Air Sampling Network of the U. S. Public Health Service, Taft Sanitary Engineering Center, the actual daily values of suspended particulates in micrograms/cubic meter have been made available for all observing stations in the Delaware Valley. Although the number of daily observations available from each sampling site ranged only from 21 days during the year at Eagleville and Princeton to 26 days at Pemberton so that the sample of data is quite small, it is possible to utilize the available data to obtain at least an indication of the distribution of air quality over the area.

Table 18

Monthly Values of Various Atmospheric Pollutants, CAMP Station Philadelphia, 1965 (after U.S. Dept. HEW, 1966)

	Average Concentration (ppm)	Maximum (ppm) 24-hr	Maximum (ppm) 1-hr	Average Concentration (ppm)	Maximum (ppm) 24-hr	Maximum (ppm) 1-hr
	Carbon Monoxide			Nitric Oxide		
January	7.6	14	26	.065	.31	.89
February	10.1	19	54	.052	.21	.69
March	7.8	13	22	.038	.11	.23
April	6.2	11	22	.028	.07	.44
May	6.9*	16*	26*	.030*	.13*	.64*
June	5.2*	9*	11*	.018*	.05*	.25*
July	4.1*	7*	10*	.020	.04	.16
August	4.7*	8*	14*	.025	.10	.39
September	8.8	12	19	.037	.12	.43
October	10.7	18	22	.059	.16	.41
November	7.0	10	14	.053	.13	.30
December	7.2	11	22	.106	.20	.70
Year		19	54		.31	.89
	Nitrogen Dioxide			Sulfur Dioxide		
January	.034	.06	.14	.154*	.43*	.84*
February	.039	.06	.10	.075	.17	.44
March	.037	.06	.09	.067	.13	.43
April	.034	.06	.13	.051	.10	.49
May	.053*	.10*	.26*	.087*	.24*	.53*
June	.042*	.08*	.13*	m	.14	.49
July	.040	.07	.14	.056	.17	.30
August	.041	.07	.20	.057	.14	.49
September	.042	.07	.13	.067	.25	.67
October	.036	.07	.12	.120	.31	.59
November	.026	.06	.10	.126	.35	.94
December	.035	.06	.13	.128	.36	.62
Year		.10	.26		.43	.94
	Total Hydrocarbons			Total Oxidants		
January	1.8	4	7.5	.018	.03	.09
February	2.6	5	9.8	.008*	.03*	.16*
March	2.0	4	5.1	.019	.03	.09
April	2.0	3	4.7	.029	.05	.10
May	2.0*	5*	10*	.036*	.07*	.14*
June	2.2*	3*	5*	.044*	.08*	.20*
July	2.2*	3*	6*	.038*	.07*	.17*
August	2.2	3	5.7	.042	.09	.21
September	2.5	3	4.5	.031	.05	.14
October	2.4	4	5.8	.026	.05	.14
November	2.1	3	4.7	.022	.03	.12
December	2.1*	4*	6*	.021	.04	.14
Year		5	10		.09	.21

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* 1964 data used instead of 1965

Table 19 gives a complete summary of the daily values of suspended particulates for 1965 in the Delaware Valley area. While the number of observations at each station is limited, some records were available for each day of the week at each station. An almost completely random sampling of suspended particulates is available for analysis. It was not possible to compare the distribution of air quality over the basin on a given day or even for a particular month because only seldom were observations made on the same days at more than a few stations. The data have, however, been summed up by quarters of the year (with 6 or 7 observations in each quarter). An average of this number of observations, randomly spaced through the quarter, provides, at least, an indication of the quantity of suspended particulates in the air at the sampling station during the quarter. Thus, average values for each three-month period and for the year as a whole are also included on the table for later use.

The table shows that the highly industrialized areas (Philadelphia, Wilmington, Newark, Sanatoga, and Hamilton in the 11-county area and Bethlehem, Reading, and Lancaster outside the area) have the highest values of suspended particulate concentration in all seasons of 1965. Annual values range from 182 $\mu g/m^3$ at Philadelphia and 143 $\mu g/m^3$ at Bethlehem to low values of 64 and 62 $\mu g/m^3$ at Embreeville and Jutland respectively. As expected, Philadelphia had the highest value of suspended particulates in each of the four quarters of the year, Wilmington was second highest in all quarters within the 11-county area, Sanatoga, Pa. was third highest in the winter and summer quarters and Princeton was third in the spring and fall quarters. Pipersville had the lowest value of suspended particulates in three of the four quarters but one particularly high value (July 9, 1965) raised its average for the third quarter above that of many other stations in the basin. Pemberton had the lowest value of suspended particulates in that quarter. Outside the area, Bethlehem and Reading were generally very high while Jutland was very low.

The distribution of air quality can be seen more clearly if these quarterly average values are plotted on maps. This has been done in figures 21a through 21e. Figure 21a shows the distribution of the average annual values of air quality at the different stations while figures 21b through 21e show the distributions of values in each of the four quarters of the year.[1]

Lines of constant suspended particulate concentration have been drawn on these maps at 20 microgram/cubic meter intervals. While one may not be justified in making this type of analysis, since the values of suspended particulates are specifically spot values and are not necessarily representative of any significant area around the observing site, the resulting patterns seem entirely consistent. High values of suspended particulate concentration occurring in the immediate Delaware River Valley area from Wilmington to Trenton can logically be inferred from the four point observations in Philadelphia and those at Newark, Wilmington, Princeton, and Hamilton and the known distribution of industries and people. The analysis of the data in areas to the east

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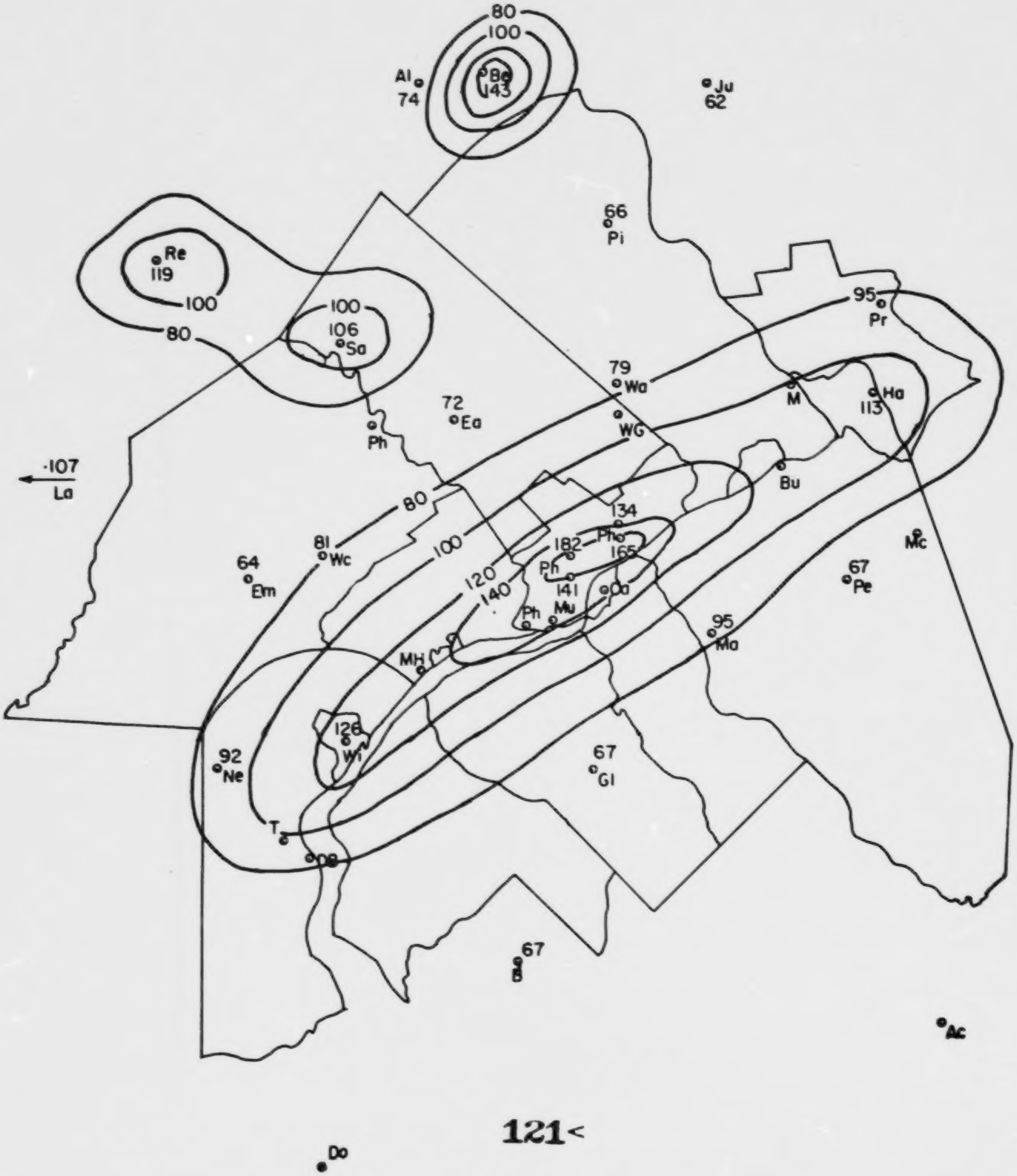
[1] The data for Philadelphia have been supplemented by including average values of suspended particulates collected daily through the year at three stations in the city by the City Health Department. These more detailed records will be referred to again later.

DISTRIBUTION OF AVERAGE SUSPENDED PARTICULATE CONCENTRATION, 1965
(Values in $\mu g/m^3$)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WG
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Pr
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Ha
113
Bu
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La
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140
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Ph
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Ph
141
Ca
Ph
Mu
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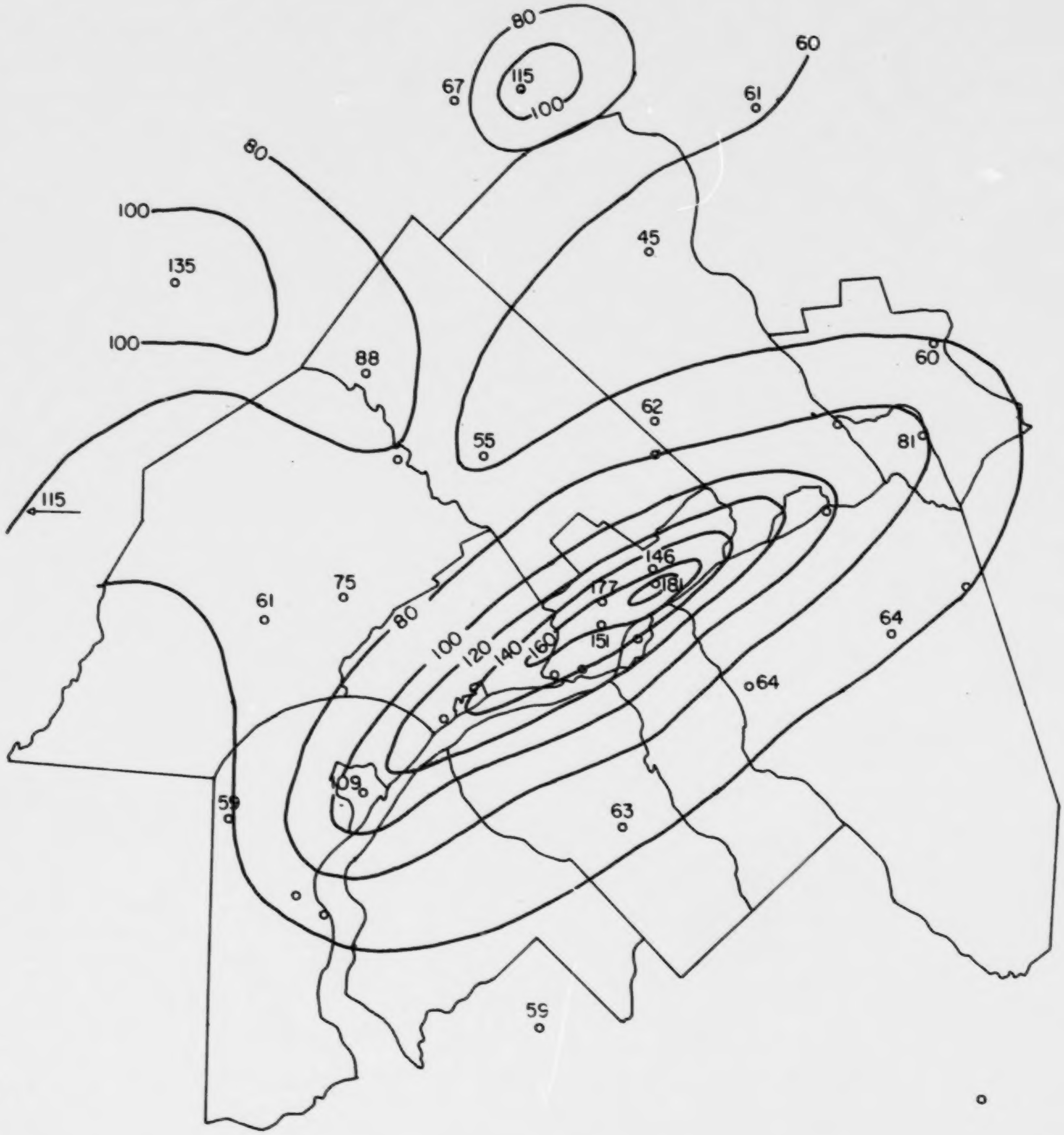
Wc
64
Em
MH
67
Mc
67
Pe
95
Ma
126
Wi
92
Ne
67
Gl
T
Ch
67
B
Ac
Do

Figure 21 a

DISTRIBUTION OF AVERAGE SUSPENDED PARTICULATE CONCENTRATION, JAN. - FEB. - MAR. 1965

(Values in $\mu g/m^3$)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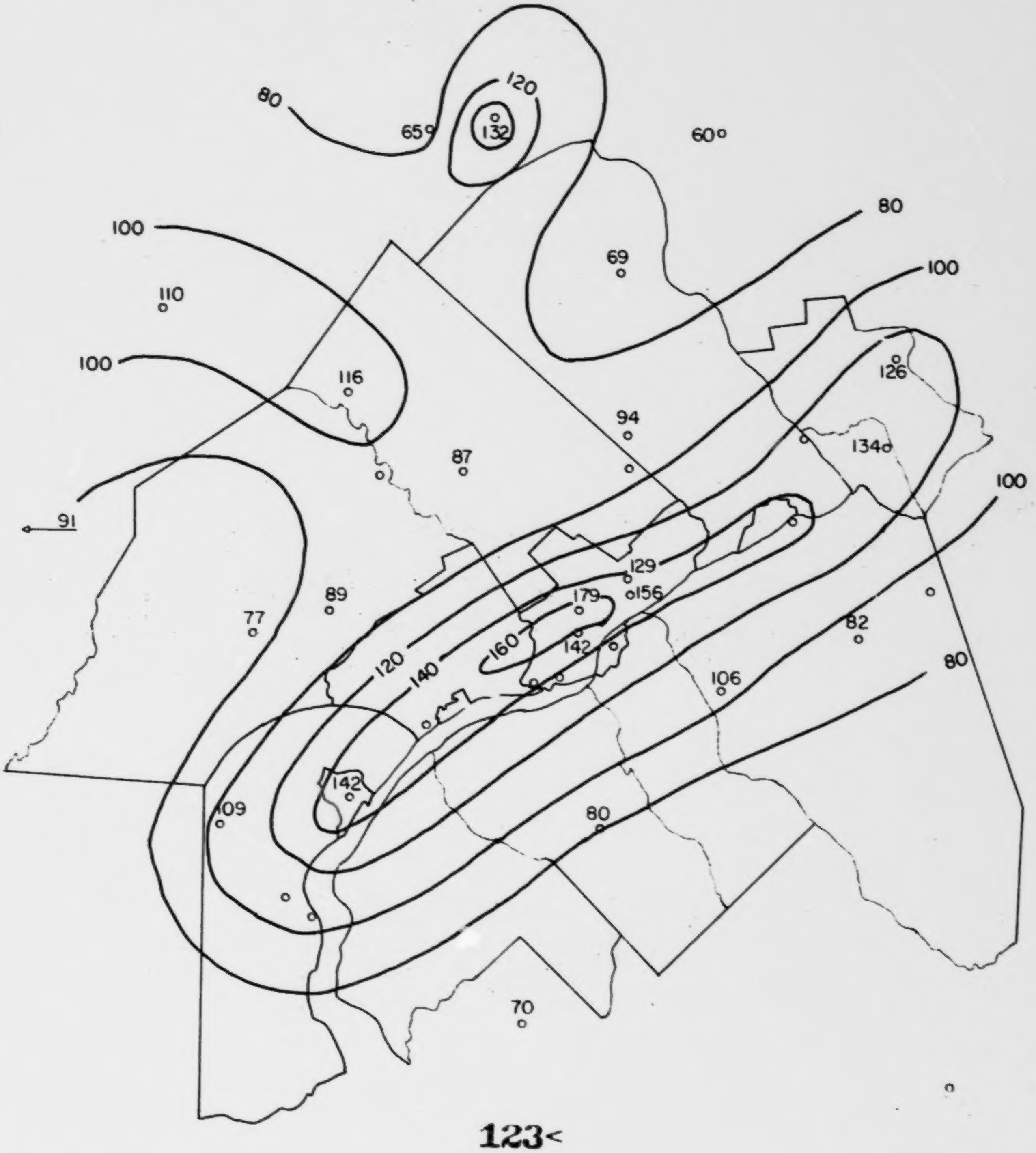
75
61
64
80
100
120
140
160
151
64
109
59
63
59

Figure 21 b

DISTRIBUTION OF AVERAGE SUSPENDED PARTICULATE CONCENTRATION, APRIL - MAY - JUNE 1965

(Values in $\mu g/m^3$)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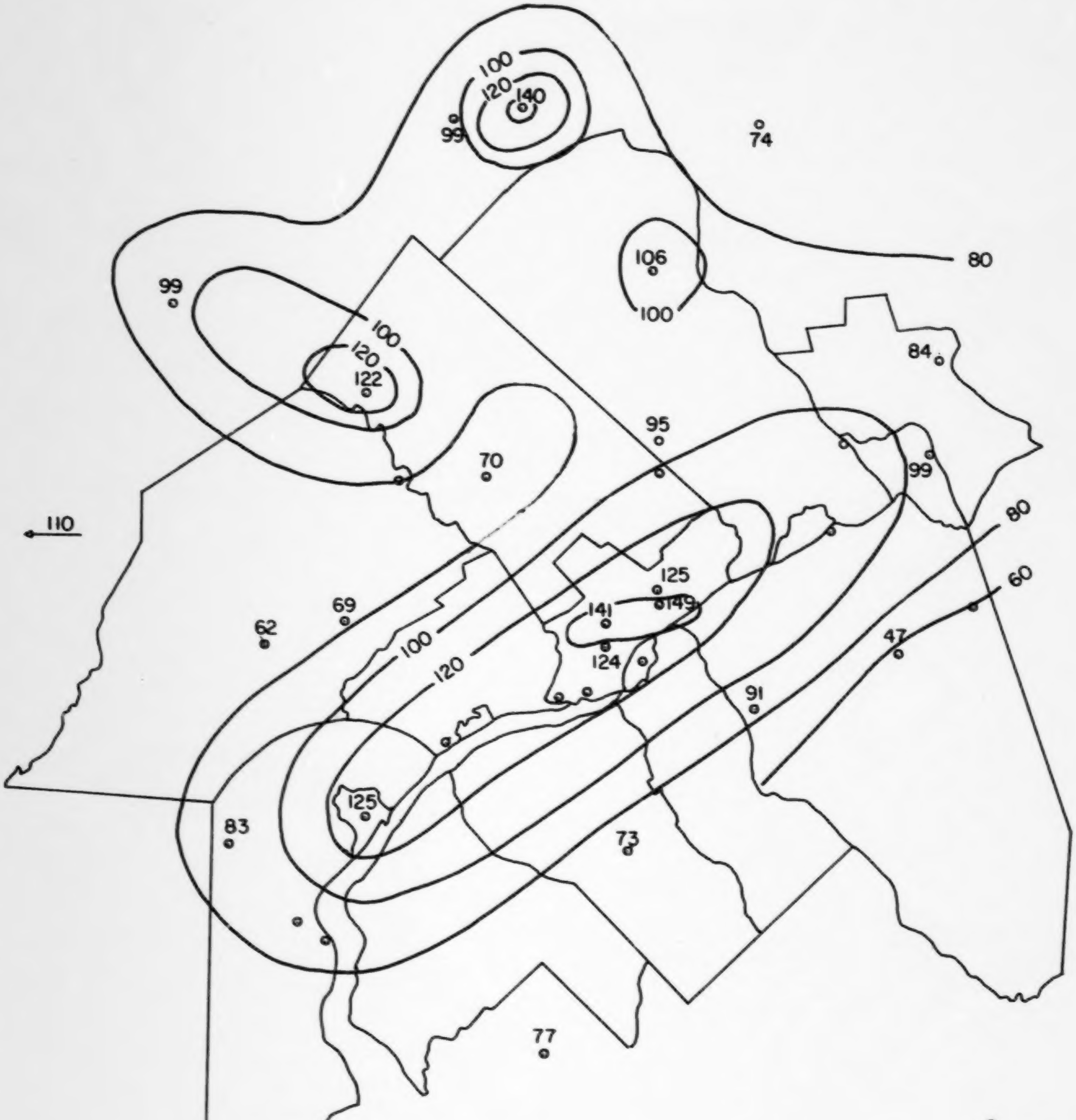
89
77
160
142
82
120
140
106
80
142
109
80
70

Figure 21 c

DISTRIBUTION OF AVERAGE SUSPENDED PARTICULATE CONCENTRATION, JULY - AUG. - SEPT. 1965

(Values in $\mu g/m^3$)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99
100
120
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95
70
99
110
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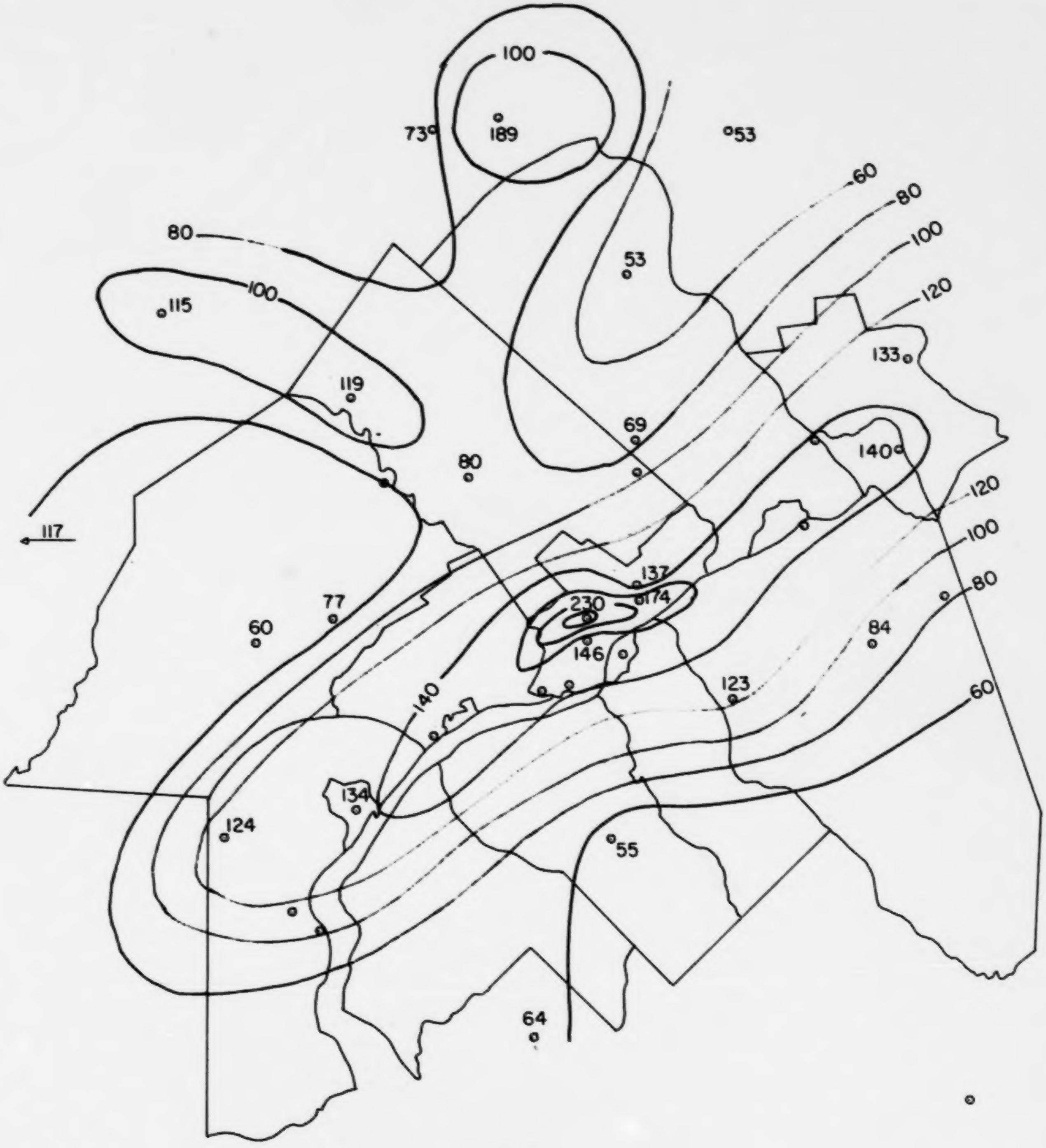
60
125
141
149
69
62
100
120
124
47
91
125
83
73
77

Figure 21 d

DISTRIBUTION OF AVERAGE SUSPENDED PARTICULATE CONCENTRATION, OCT. - NOV. - DEC. 1965
(Values in $\mu g/m^3$)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100
80
53
100
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133
119
69
140
80
117
120
100
137
230
174
80
77
60
146
84
123
140
60
134
124
55
64

Figure 21 e

Table 19

Daily and Seasonal Values of Suspended Particulate Concentration ($\mu g/m^3$)
at All Available Delaware Valley Sampling Stations, 1965

	Cities in the 11-County Study Area														Cities Outside the 11-County Study Area					
Date	New.	Wil.	Gla.	Ham.	Mar.	Pem.	Pri.	Eag.	Emb.	Phi.	Pip.	San.	War.	W.C.	All.	Bet.	Lan.	Rea.	Bri.	Jut.
January																				
4				97	113	39									92				68	
5		130								269										
6			74																	
7																				106
13																	204			
16									46	98		55		51						
17	44		51	38		57													50	
18								58								107	79			
19		101																		
20									54					49						
21							65					89			64					
22																		273		
23																				33
29		138				89						74		79						
30	57						107								81	153	133		65	
31								94	84											
February																				
2							81													
3										167						120				
4					91													139		
5			70																	
7																		93		
8	64																			
9																				36
16			84																	
18						63					30		58	86						
19	64			99	47		64	24	70			104				113	79	123	44	
20															64					
21																				112
24		83								258	60		78							
28	81				77	58	32	46			69		91			103	125	102	95	

126<

Table 19
(continued)

Date	Cities in the 11-County Study Area														Cities Outside the 11-County Study Area					
	New.	Wil.	Gla.	Ham.	Mar.	Pem.	Pri.	Eag.	Emb.	Phi.	Pip.	San.	War.	W.C.	All.	Bet.	Lan.	Rea.	Bri.	Jut.
May																				
1	90																			
9			82		118						65	77	106			135	101	114	61	
10	110													106						
11		228					176	127		233										109
18															92					
22						87			114			149								
23						107														
26											49	150								
27			70	138	103	87			67					86		109		107		
28	118	127					81	82									90			
29															69					
31																				71
June																				
3										72										
6						54														
8											62		92							
9								61	45	170		90		39					39	
10	48	84			77	52	217									119	85	87		
11				118																
15																				40
16						28														
17																			60	
21												189								
22			89	200	186	105				223	106		114		85	218		167		
23	177							121									93			
29		118																		89
Second Quarter Mean	109	142	80	134	106	82	126	87	77	179	69	116	94	89	65	132	91	110	70	60

Table 19
(continued)

Date	Cities in the 11-County Study Area														Cities Outside the 11-County Study Area					
	New.	Wil.	Gla.	Ham.	Mar.	Pem.	Pri.	Eag	Emb.	Phi.	Pip.	San.	War.	W.C.	All.	Bet.	Lan.	Rea.	Bri.	Jut.
July																				
2			51						48					65						
3						38		95									71	72		
6	59																			
7					119															
8																124				
9									72		162	117	102	68						
10						60														
11																				37
19									56					58					74	
20	140		31				41										81			
21				65	76					113										
26										114			73							
28		131																		
August																				
5						35	42	53		183				94					65	
10		78																		
12											78	55	101							
14					125	49			75	177				85		154		125	115	
15	110																129			
16											141	155	146							133
18		130																66		
19			165																	
23															79					
26				144																
September																				
2					78	67	58	56	61	136				61		142			72	
3	61			120																
4		173																		
6																				48
7															104					
8											107	162	104				171			
13	54		55	63	58	39			57					57	113	193	88	104	52	
14										125										

Table 19
(continued)

	Cities in the 11-County Study Area														Cities Outside the 11-County Study Area					
Date	New.	Wil.	Gla.	Ham.	Mar.	Pem.	Pri.	Eag.	Emb.	Phi.	Pip.	San.	War.	W.C.	All.	Bet.	Lan.	Rea.	Bri.	Jut.
September (continued)																				
16								75												
18																		101		
21							163													79
22			56	119																
26						41														
27	74		79	82			114							60		89		129	82	
28		112																		
29															101		117			
30											41		45							
Third Quarter Mean	83	125	73	99	91	47	84	70	62	141	106	122	95	69	99	140	110	99	77	74
October																				
4																				24
7										215										
8	68					27		35	37										33	
9			36	86							36		50	34	31		47			
12																		92		
13								79												
14																202				
18																				92
19					129															
26	150		54	160	138	84	136		65							183		103	55	
27		97						105			50		73							
28																	84			
30												73			61					
November																				
1																				44
6			57		101	68	159	101	55	272					109	217		165	71	
7												109								
8	100			98																
10											68		92				134			
13														61						
15																				35

Table 19
(continued)

	Cities in the 11-County Study Area														Cities Outside the 11-County Study Area					
Date	New.	Wil.	Gla.	Ham.	Mar.	Pem.	Pri.	Eag.	Emb.	Phi.	Pip.	San.	War.	W.C.	All.	Bet.	Lan.	Rea.	Bri.	Jut.
November (continued)																				
19		135																		
21	121		61		106	59	117		69	186		78		95	82			153	63	
22				96													156			
23		115														139				
24													66							
29																				45
December																				
1											59									
7			32		72	117			30	114		137		52					67	
8				189											68	161	61	119		
9	131						119													
13																				25
14		175									34									
15													48							
22	171		90	211	192				103	279		196		143	89	230	220	158	92	
23		147																		
28						149							85							
29										312	72									
30																				104
Fourth Quarter Mean	124	134	55	140	123	84	133	80	60	230	53	119	69	77	73	189	117	115	64	53
Annual Average	92	126	67	113	95	67	95	72	64	182	66	106	79	81	74	143	107	119	67	62

Identification of Cities:

New. - Newark, Del
Wil. - Wilmington, Del.
Gla. - Glassboro, N.J.
Ham. - Hamilton, N.J.
Mar. - Marlton, N.J.
Pem. - Pemberton, N.J.
Pri. - Princeton, N.J.

Eag. - Eagleville, Pa.
Emb. - Embreeville, Pa.
Phi. - Philadelphia, Pa.
Pip. - Pipersville, Pa.
San. - Sanatoga, Pa.
War. - Warminster, Pa.
W.C. - West Chester, Pa.

All. - Allentown, Pa.
Bet. - Bethlehem, Pa.
Lan. - Lancaster, Pa.
Rea. - Reading, Pa.
Bri. - Bridgeton, N.J.
Jut. - Jutland, N.J.

and west of the immediate river valley is open to more question. The position of the isolines in these areas is quite hypothetical and is based on the assumption that the average seasonal values found at stations removed from local heavy industrial concentrations are representative of a considerable body of air around each of the stations. If certain of these values are, in fact, influenced appreciably by some local industrial or population source of pollution, this assumption becomes invalid and the analysis lacks justification in those areas.

Figure 21a shows a possible annual distribution of average air quality in the 11-county area based on values of suspended particulates in micrograms/cubic meter for 1965. The center of pollution is the city of Philadelphia with a fairly narrow band of high values of suspended particulates running northeast-southwest along the highly industrialized river valley from just south of Wilmington to just north of Trenton. This band does not extend to any great degree in a northwest-southeast direction as is shown by the much lower values of suspended particulates at Glassboro and Pemberton to the southeast and Eagleville and Warminster to the northwest. A secondary high area of suspended particulates is found in the vicinity of Sanatoga, located just east of Pottstown, in western Montgomery county. Local industrial and population sources in this area evidently result in a higher value than is found generally over central Chester, Montgomery, or Bucks counties.

While the northeast-southwest orientation of high values of suspended particulates might be expected, the rather rapid decrease in concentration of suspended particulates to the east and west of this band of high concentration is less expected. Wind rose data show the high frequency of westerly winds. Under conditions of winds from the northwest quadrant, which occur on the order of 30 percent of the time, one would expect the band of high pollution to spread eastward across parts of Gloucester, Camden, and Burlington counties. Even with winds from the southwest quadrant, which are equally as common as northwest winds, pollution from Philadelphia, Marcus Hook, Chester, and Wilmington sources might be expected to move northeastward over parts of Camden and Burlington counties. The fact that Pemberton in Burlington county has a relatively low value of suspended particulates (about the same as Embreeville and Pipersville well to the west of the urban-industrial pollution sources of the river valley) would lead one to infer that the areal movement or spread of suspended particulates is quite limited and that these pollutants are removed from the air fairly rapidly as the air moves from the source to the receiving area.

Less reliance can be placed on the maps of seasonal air quality (figures 21b through 21e) because of the fewer number of observations that comprise the average. However, the pattern of distribution on each seasonal map is quite similar to the pattern found on the annual map, and this might suggest a certain stability and reliability in the pattern. Several minor changes can be noted on these maps.

1) There is a significant increase in suspended particulate concentration at all stations from the January-February-March map to the April-May-June map. While the distribution pattern is the same, the area covered by the 100 $\mu g/m^3$ isoline covers twice

as much area on the spring map as on the winter map. This would not normally be expected as spring conditions usually lead to a decrease in pollution potential. It is evidently related to local weather and pollution events during 1965.

2) Particularly high values of suspended particulates were found at Pipersville and Sanatoga in the summer quarter while values of suspended particulates in Philadelphia reached their low for the year. Lower summertime values of suspended particulates might be expected on the basis of less home and industrial heating needs, greater radiative heating during the day, and increased turbulent mixing in the air. The values at Pipersville and Sanatoga evidently reflect some local influence at that time.

3) A marked increase in suspended particulate concentration was found at Philadelphia, Hamilton, Princeton, Marlton, and Pemberton on the October-November-December quarter map. This, in part, can be related to a significant period of stable atmospheric conditions and high atmospheric pollution during the last 10 days of December 1965 during which two observations were taken at Philadelphia, and one each at Marlton, Hamilton, and Pemberton. These observations were the highest for the year at these stations and, of course, influenced the averages significantly. The high pollution at that time was not confined to the northeast sector of the 11-county area since high values of suspended particulates were also found at Newark, Sanatoga, and Bethlehem.

Daily Variations in Air Quality

Because of the relation between air quality and industrial activity or the movement of people by automobiles, a strong weekly bias in air quality might be anticipated. Values of low atmospheric pollution concentrations on the weekends are usually attributed to low industrial activity or fewer automobiles on the highways rather than to the influence of favorable atmospheric mixing conditions. In order to study the weekly course of suspended particulate concentration, the previously analyzed values of suspended particulates at the available stations in the 11-county study area were regrouped by day of the week regardless of season. Table 20 gives the average for each day of the week at each station as well as for all stations. While only two to three observations were available on certain days at some stations, the averages for all stations are based on more than 29 observations for each day of the week and so might be considered fairly stable.

The change in average values of suspended particulates through the week is surprisingly small, ranging from a high value of 104 $\mu g/m^3$ on Tuesday to a low value of 82 $\mu g/m^3$ on Sunday. The values are so constant that only 6 $\mu g/m^3$ separate Monday, Thursday, Friday, Saturday, and Sunday. Thus, there appears to be only a slight weekend lowering of suspended particulate concentration in the Delaware Valley area, based on the random sampling of 20-25 days in

Table 20

Average Suspended Particulate Concentration by Day of Week, Delaware Valley Area, 1965

Station	M	T	W	T	F	S	S
Newark	87 (5)*	116 (3)	128 (3)	82 (3)	81 (3)	73 (2)	85 (5)
Wilmington	-	131 (10)	93 (5)	115 (3)	136 (4)	173 (1)	-
Glassboro	67 (2)	58 (7)	67 (5)	118 (2)	60 (2)	61 (3)	65 (3)
Hamilton	87 (5)	130 (4)	141 (6)	116 (4)	112 (3)	86 (1)	38 (1)
Marlton	86 (2)	104 (6)	108 (4)	79 (6)	47 (1)	113 (2)	100 (3)
Pemberton	39 (2)	114 (4)	50 (2)	61 (5)	61 (3)	57 (6)	70 (4)
Princeton	114 (1)	96 (7)	-	90 (6)	87 (3)	133 (2)	74 (2)
Eagleville	60 (3)	127 (1)	72 (6)	61 (3)	47 (3)	100 (3)	70 (2)
Embreeville	56 (2)	54 (5)	62 (4)	66 (3)	67 (4)	73 (4)	74 (2)
Philadelphia	114 (1)	176 (8)	210 (8)	152 (4)	-	182 (3)	186 (1)
Pipersville	141 (1)	55 (5)	65 (9)	50 (3)	162 (1)	49 (3)	69 (1)
Sanatoga	135 (4)	137 (1)	134 (5)	70 (3)	98 (3)	92 (3)	88 (3)
Warminster	109 (2)	75 (5)	71 (7)	68 (3)	110 (2)	53 (2)	99 (2)
West Chester	70 (4)	88 (3)	49 (3)	69 (4)	91 (4)	68 (2)	-
Average	87	104	102	85	88	87	82

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*Numbers in ( ) indicate number of observations used in average.

1965. The interesting figure is the value of 85 $\mu g/m^3$ found on Thursday. This day might be expected to have the high value for the week on the basis of the buildup of industrial pollution during the week but such was not found in this study of selected random data.

The Philadelphia Department of Public Health, Environmental Health Laboratory has been making daily observations of suspended particulates with a vertical high volume air sampler, and daily measurements of soiling index with an AISI smoke sampler at three locations within the city for the last few years. Mr. Robert Beman, the Director of the Laboratory, has kindly made the results for 1965 available for study on this contract. Two of the sampling sites are in the northeastern part of the city (3200 Frankford Avenue and 1501 East Lycoming) while the third sampling site is just south of the center city area at 500 South Broad Street.

The daily values of suspended particulates and of the soiling index at the three sites are included in Appendix C for reference. Based on the available data, the monthly averages of suspended particulates and soiling index and the variation of these factors through the week (using daily data for the whole year) are given in tables 21 and 22. The actual daily values of both

Table 21

Average Monthly Values of Suspended Particulates and Soiling Index at Three Philadelphia Sampling Stations, 1965

Location	J	F	M	A	M	J	J	A	S	O	N	D	Y
Suspended Particulates ($\mu g/m^3$)													
3200 Frankford	196	193	160	140	173	156	138	148	159	160	158	202	165
1501 E. Lycoming	169	156	112	114	144	127	118	127	129	128	125	158	134
500 S. Broad	167	152	139	141	152	132	125	112	134	139	135	165	141
Soiling Index (COHS/1000 ft x 100)													
3200 Frankford	175	156	130	112	87	86	75	82	100	136	147	182	122
1501 E. Lycoming	130	94	64	59	55	77	66	73	66	88	103	177	88
500 S. Broad	144	131	97	77	56	58	60	61	71	88	110	146	90

Table 22

Average Values of Suspended Particulates and Soiling Index at Three Philadelphia Stations, 1965, by Day of Week

Location	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.	Sun.
Suspended Particulates ($\mu g/m^3$)							
3200 Frankford	163	179	187	185	188	138	119
1501 E. Lycoming	138	150	147	151	145	110	95
500 S. Broad	140	146	148	170	146	127	110
Soiling Index (COHS/1000 ft x 100)							
3200 Frankford	119	130	133	139	137	104	89
1501 E. Lycoming	85	92	100	104	97	75	60
500 S. Broad	91	96	97	97	97	83	71

suspended particulates and soiling index have been plotted on figures 22 and 23 and will be discussed in more detail in a later paragraph. The pattern of monthly variation in suspended particulates based on daily data (table 21) shows high values in the winter months of December through February. There is a rapid decrease in suspended particulate concentration in March and April with a secondary peak value in May. Low values again are found in the summer months of June, July, and August while the fall witnesses a slow increase in suspended particulate concentration back to the winter peaks. While there is a definite seasonal change from the high winter to the lower summer values of suspended particulate concentration, the secondary maximum in May and minimum in March and April result in an oscillating pattern through the year. On the basis of the 1965 monthly and annual values, the area around 3200 Frankford Avenue in northeast Philadelphia is subject to higher values of suspended particulate concentration than the other sampled areas. The actual values are a result of local influences.

Soiling index, obtained from AISI samplers at the three Philadelphia stations, shows a more marked seasonal contrast with highest values in winter, lowest values in summer, and lower values in spring than in fall. This pattern is repeated at all three Philadelphia sampling stations. Again, the Frankford Avenue station has the highest totals of soiling index in each month of the year.

When the daily values of suspended particulates and soiling index are separated on the basis of day of the week, a day-to-day variation is found which would be anticipated on the basis of industrial and automobile activity. Table 22 shows lowest values of suspended particulate concentrations at all three stations on Sunday as would be expected. Values increase during the week reaching a maximum value on Friday at 3200 Frankford Avenue, and Thursday at the other two stations. As industrial and automobile activity is curtailed over the weekend, the values of suspended particulates decrease again. The soiling index follows the same pattern from lowest values on Sunday to highest values on Thursday.

The pattern of air quality through the week, based on values from each day of the year (table 22) and based on just 20-25 samples in the whole year (table 20), points out the difficulty in trying to draw too many conclusions from limited and isolated point data. The data from samplers in Philadelphia, or from any other place with appreciable industrial or automobile activity would be expected to show a fairly strong weekly variation, while the data from a suburban or a more rural area would not necessarily show such a significant bias. Thus, since the limited-data study of table 20 included many stations in suburban and rural areas, the conclusion that there is little weekly bias is justified. The daily values, based on both urban and suburban stations, in table 20 indicates a fairly uniform and generally moderate concentration of suspended particulates in the atmosphere over the whole basin regardless of day of the week. Daily differences through the week are found in areas of industrialization and population due to local work and travel habits (table 22).

Because there are fairly significant seasonal changes in concentrations of soiling index and suspended particulates as well as large day-to-day changes, it was felt that periods of significantly high and low atmospheric pollution could best be identified by obtaining long-period means of the available data and noting periods of marked deviation from the long-period mean values. For the purposes of this study, 20-day moving means of the data for each Philadelphia station were obtained and plotted on calendar paper. The results for the soiling index are shown in figures 22a-c and for the suspended particulate concentration in figures 23a-c.

In addition to the 20-day moving means, which remove much of the short-period variability from the data, points have been plotted on each diagram to indicate a deviation of ±25 percent from the moving mean. Finally the actual daily values are included on the diagram so that it is possible to see short-period fluctuations in relation to the longer-term, weekly or seasonal fluctuations. Periods during which daily values of soiling index or suspended particulates exceed the 20-day moving mean by ±25 percent for at least two consecutive days are marked by appropriate symbols on each diagram. These are significant periods for they indicate considerable time periods with much above or below normal (for the season) atmospheric pollution. These periods will be investigated more fully in a later section of this report.

Analysis of the seasonal course of daily soiling index values for the three Philadelphia stations (figures 22a-c) reveals several interesting changes that occur:

1) Day-to-day variations in soiling index are much greater in the fall and winter season of the year than in spring and summer.

2) There is a seasonal change in the average value of soiling index from a high point in late December or early January to a low point in May, June, or July.

3) Periods of significant deviation from the 20-day moving mean are found in all seasons of the year, but they are more frequent in the fall and winter season than they are in the summer season.

4) There is a larger day-to-day variation in soiling index in the northeast part of the city than in the south-central part, although the annual range of the 20-day mean values is about the same at all three sampling sites. Thus local sources do influence day-to-day readings, but the longer-term picture is more influenced by the general environmental location than by strictly local conditions.

Figures 23a-c show the seasonal course of suspended particulates on a day-to-day basis and by means of 20-day moving means at the same three Philadelphia sampling sites. The seasonal pattern is not as obvious. While the highest values of suspended particulates were measured in January, the lowest values on the basis of the 20-day moving means were found in late March. Secondary high values occurred again in May. Thus, there is a variation through the year but it does not seem to be related to seasonal climatic changes.

Day-to-day variations in suspended particulate concentration were much greater in winter than in summer although appreciable variations occurred in all seasons of the year.

Periods with two or more consecutive days with values of suspended particulates well above or below the 20-day moving mean were distributed through the year in much the same manner as they were with the soiling index values. Wintertime had somewhat more periods with high values of suspended particulates than did the other seasons of the year.

Periods of Significantly High or Low Air Pollution

In order to identify periods of significantly high or low concentrations of atmospheric pollutants, the daily records of soiling index and suspended particulates from the Philadelphia stations and of nitrogen dioxide and sulfur dioxide from the one Philadelphia CAMP station were studied. Periods during which the actual soiling index and the suspended particulate concentration exceeded the 20-day moving mean by more than 25 percent for at least 48 consecutive hours have already been identified on the graphs of figures 22 and 23. Since some of these periods were the result of local contamination rather than periods of general high pollution over the area, a condensed list was

DAILY COURSE OF SOILING INDEX AT 3200 FRANKFORD AVE., PHILADELPHIA, PA.- 1965

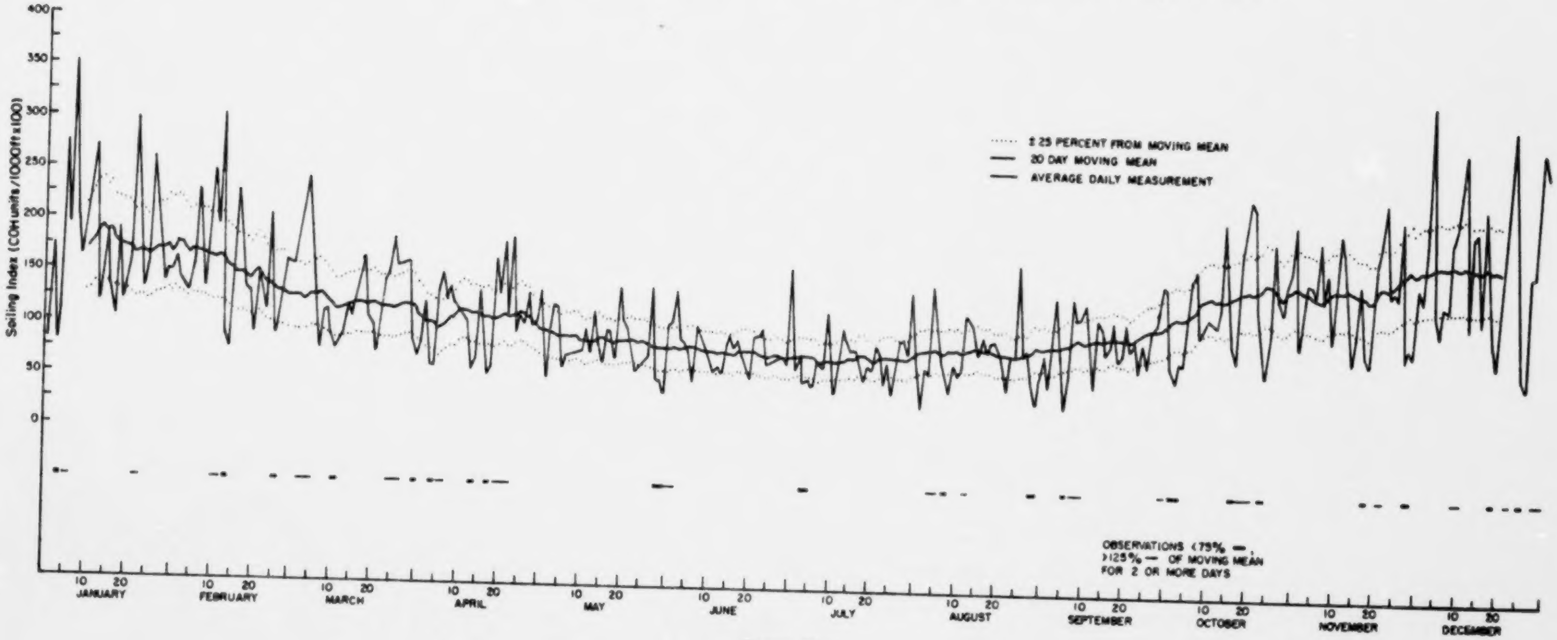

Figure 22a

DAILY COURSE OF SOILING INDEX AT 1501 E. LYCOMING ST., PHILADELPHIA, PA. - 1965

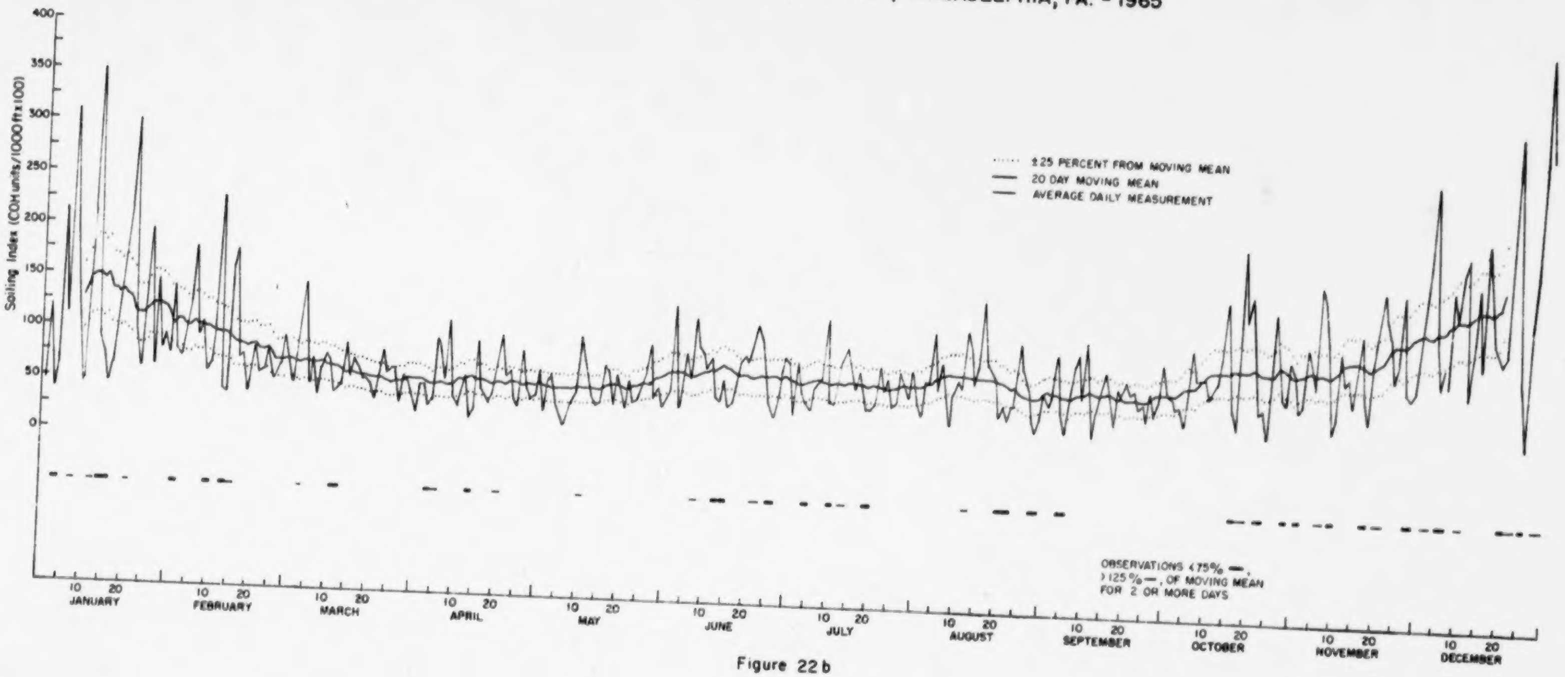

Figure 22b

DAILY COURSE OF SOILING INDEX AT 500 S. BROAD ST., PHILADELPHIA, PA. - 1965

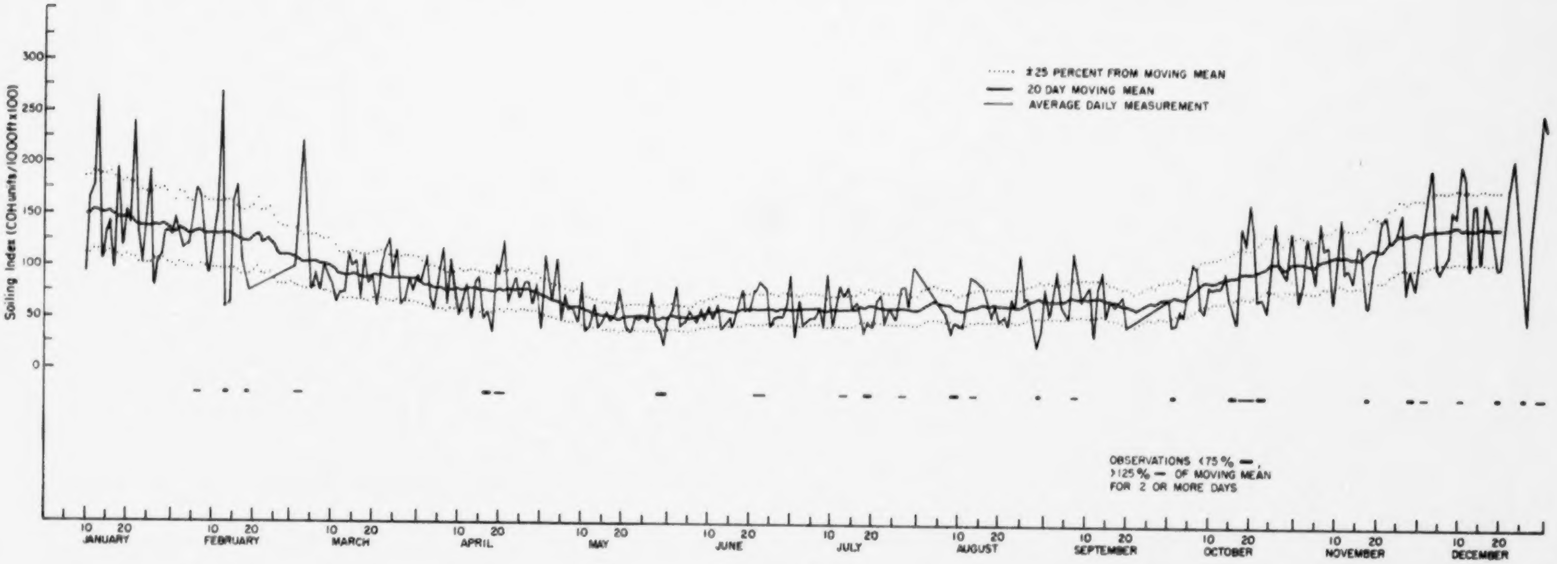

Figure 22c

DAILY COURSE OF SUSPENDED PARTICULATE CONCENTRATION AT 3200 FRANKFORD AVE. PHILADELPHIA, PA. - 1965

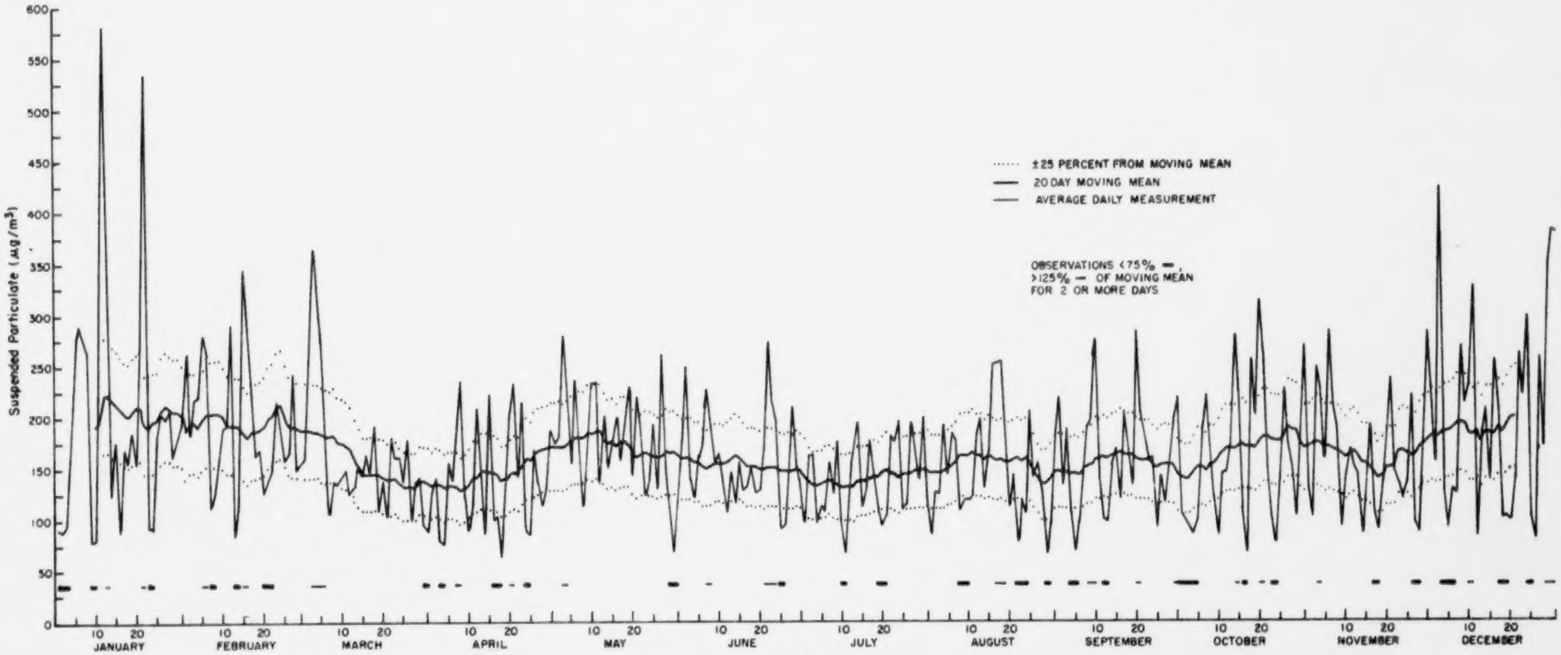

Figure 23 a

DAILY COURSE OF SUSPENDED PARTICULATE CONCENTRATION ($\mu G/M^3$) AT 1501 E. LYCOMING ST., PHILADELPHIA, PA. - 1965

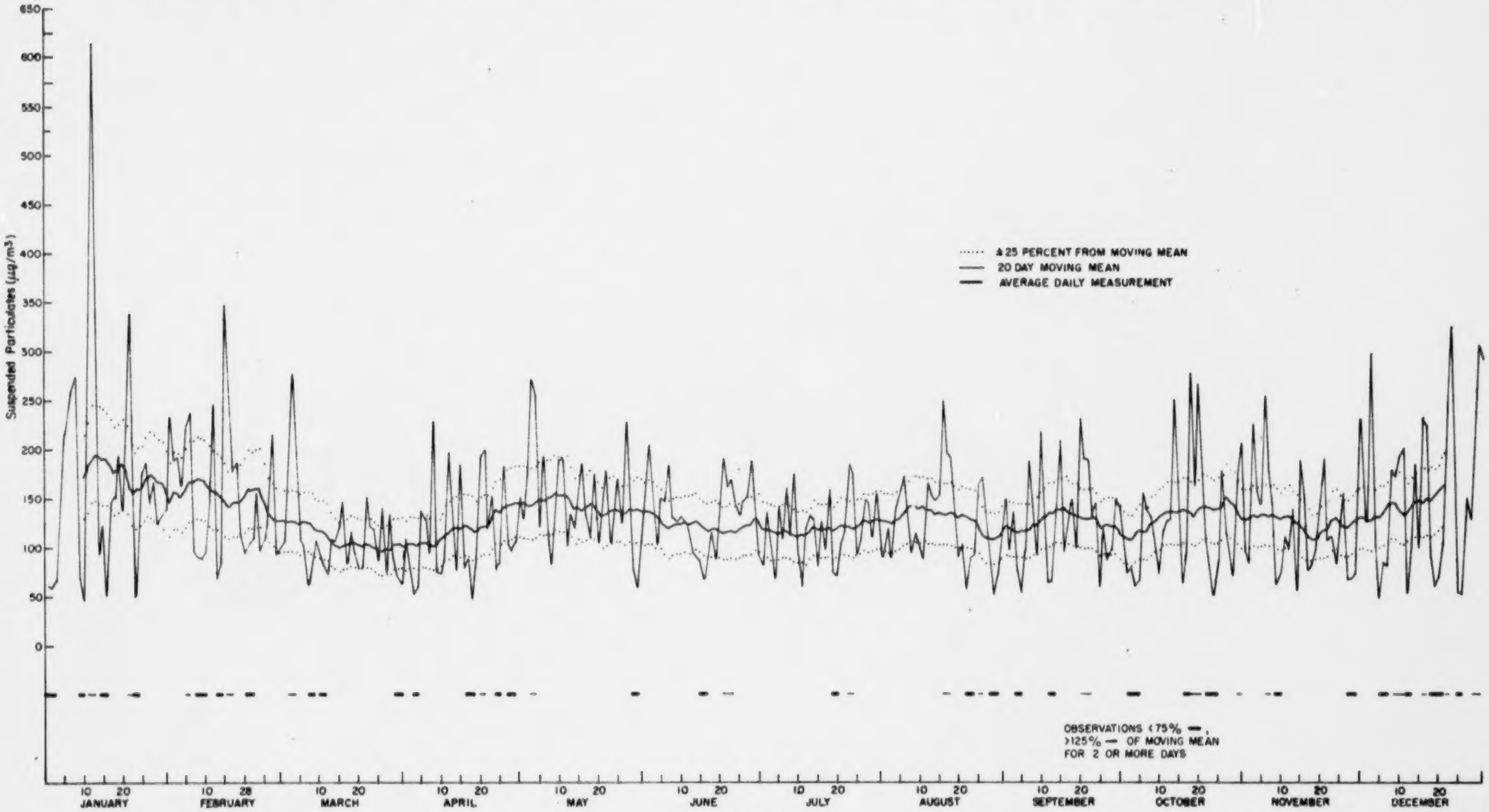

Figure 23 b

DAILY COURSE OF SUSPENDED PARTICULATE CONCENTRATION AT 500 S. BROAD ST. PHILADELPHIA, PA. - 1965

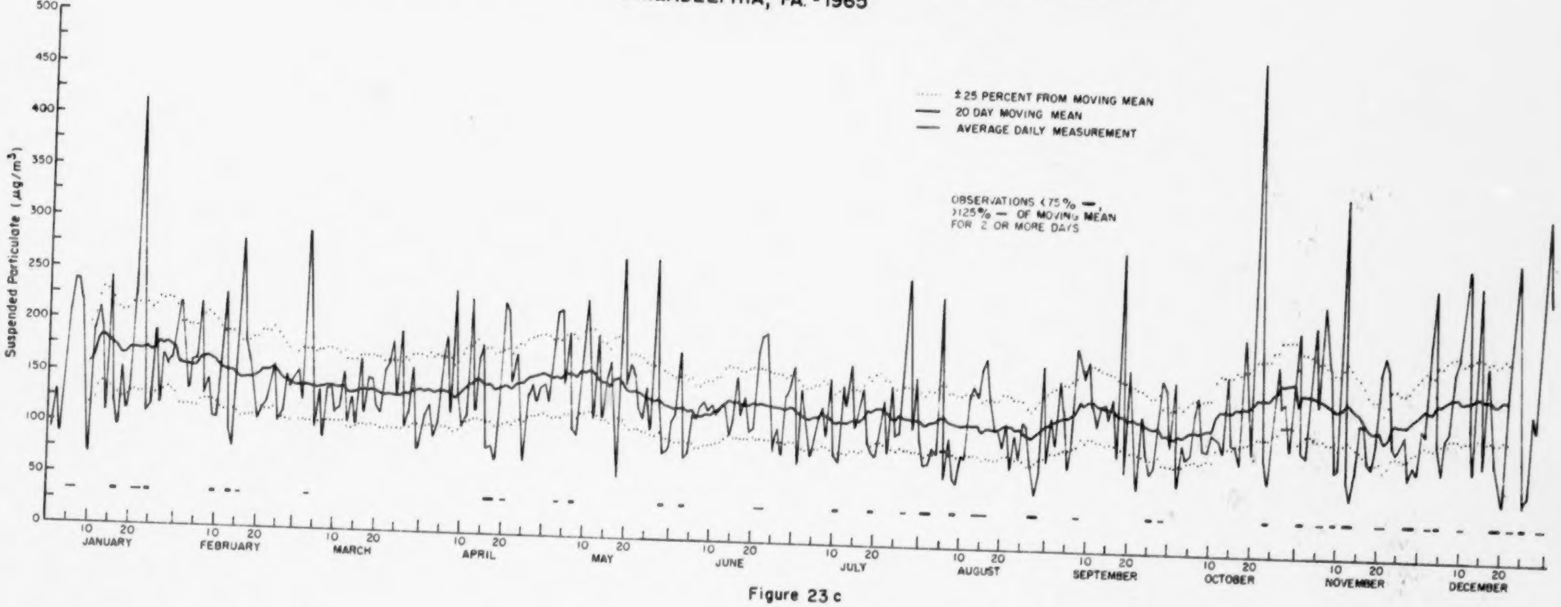

Figure 23 c

prepared which included only those periods during which excessively high values of soiling index or suspended particulates occurred at two or all three of the sampling sites at the same time. This resulted in a list of 15 periods, totaling 34 days, of much above normal values of the soiling index in Philadelphia in 1965 and 11 periods, totaling 14 days, with much below normal values of soiling index. Seventeen periods totaling 35 days, had much above normal values of suspended particulate concentration while 13 periods, totaling 20 days, had much below normal values of suspended particulates. The actual dates are tabulated in table 23.

Table 23

Dates in 1965 with Significant Concentrations of Different Atmospheric Pollutants

a) Much Above Normal Values

Soiling Index	Suspended Particulates	NO$_2$*	SO$_2$*
Jan. 7-8	Jan. 12	Jan. 12-13	Feb. 5-6-7
Jan. 22	Jan. 21-22	Feb. 15-16	Feb. 10-11-12
Mar. 2-3-4	Feb. 5-6	Mar. 3-4	Mar. 2-3-4-5-6
Apr. 5-6	Feb. 15-16	Apr. 20-21-22-23	Mar. 25-26
Apr. 20-21	Mar. 2-3-4	July 13-14	Apr. 21-22-23
June 21-22-23	Apr. 20-21	July 27-28-29-30	Aug. 25-26-27
July 13-14	May 3-4	Aug. 15-16	Sept. 22-23-24
Aug. 12-13	June 21-22-23	Sept. 7-8	Sept. 28-29-30
Sept. 7-8	Aug. 16-17-18	Sept. 27-28-29	Oct. 8-9
Oct. 18-19-20-21	Sept. 8	Oct. 18-19-20-21	Oct. 14-15
Nov. 21-22	Sept. 20-21	Nov. 4-5-6-7-8	Oct. 20-21
Dec. 2-3	Sept. 29	Nov. 10-11	Nov. 3-4
Dec. 10-11	Oct. 20-21	Nov. 15-16	Nov. 6-7
Dec. 22-23	Nov. 6-7	Dec. 10-11	Nov. 20-21
Dec. 29-30-31	Dec. 10-11	Dec. 22-23-24	Dec. 10-11
	Dec. 22-23		Dec. 29-30-31
	Dec. 29-30-31		

Days of High Concentration of All Four	Days of High Concentration of Three of Four
Mar. 3-4	Mar. 2
Apr. 21	Apr. 20
Oct. 20-21	Sept. 8
Dec. 10-11	Sept. 29
	Nov. 6-7
	Dec. 22-23
	Dec. 29-30-31

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*No observations in May or June

Table 23
(continued)

b) Much Below Normal Values[1]

Soiling Index	Suspended Particulates	NO$_2$*	SO$_2$*
Jan. 4	Feb. 8-9-10	July 19-20	Jan. 19-20
Mar. 11-12	Feb. 22	Aug. 9-10-11	Feb. 19
Apr. 13-14	Mar. 29-30	Sept. 13	Mar. 30-31
May 28	Apr. 16	Oct. 4-5	Apr. 13-14
July 19-20	July 19-20	Oct. 25	Apr. 16
Aug. 30	Aug. 9	Oct. 28-29	July 19-20-21
Oct. 1	Aug. 23	Nov. 22-23-24-25	Aug. 9
Oct. 22	Sept. 13	Dec. 17	Sept. 1-2
Nov. 17-18	Oct. 4-5		Sept. 13-14-15-16-17
Nov. 29	Nov. 9-10		Oct. 4-5
Dec. 20	Nov. 29		Oct. 22
	Dec. 6-7		Oct. 27-28-29
	Dec. 20		Nov. 1-2
			Nov. 17-18-19
			Nov. 23-24
			Nov. 29-30
			Dec. 6-7
			Dec. 20-21

Days of Low Concentration of all Four	Days of Low Concentration of Three of Four
July 19-20	Aug. 9
	Sept. 13
	Oct. 4-5
	Nov. 29
	Dec. 20

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[1] Eliminating Saturdays, Sundays, and holidays.

*No observations in May or June

Combining the four lists of days with above normal concentrations of pollution, only four periods (7 days) were found with high concentrations of all four factors - soiling index, suspended particulate, NO$_2$, and SO$_2$. These four periods have been studied in some detail in order to determine the meteorological conditions that might have resulted in such poor air quality. Seven periods (11 days) had high concentrations of three of the four parameters. Only one period of two days duration experienced much below normal values of all four factors while 5 period with a total of 6 days had much below normal concentrations of three of the four.

There were a total of 152 days during 1965 in Philadelphia that had above normal concentrations of soiling index, suspended particulates, NO_2 or SO_2. Of these 152 days, only 18 experienced much above normal values in three out of the four pollution parameters while only 7 experienced much above normal values of all four. It is clear that more than just meteorological factors cause limiting pollution conditions to develop in an area. Serious pollution conditions as far as suspended particulates are concerned, for example, do not necessarily mean that serious pollution concentrations of NO_2 or SO_2 or even soiling index will also exist. There are undoubtedly meteorological conditions (to be described more fully in the next section) that will result in high values of nearly all major categories of pollution but these are fairly unique. Many other combinations of meteorological conditions combined with other limiting environmental conditions will result in high concentrations of one or more pollution parameter but not all pollution parameters. This makes it difficult to define the relationship between air pollution and meteorology because it becomes necessary to specify what aspect of pollution (suspended particulates, NO_2, SO_2, etc.) is being considered. Different relationships are evidently involved and meteorological conditions leading to limiting conditions in one factor will not result in limiting conditions in another.

General Atmospheric Circulation Patterns and Air Quality(1) (2)

Weather conditions during the periods of very high and very low air quality have been investigated in some detail in an effort to learn more about the type of meteorological situation associated with high and low air pollution potential.

a) Low Pollution Levels

For each of the eleven periods of much below normal soiling index in 1965, the general weather pattern over eastern United States was examined using the Weather Bureau's "Daily Weather Map" series. In eight of the eleven cases, the meteorological factors affecting the Philadelphia area were remarkably similar. The typical period of below normal pollution began with the passage of a cold front over Philadelphia. The front extended southward from a low pressure center over New England or southeastern Canada. The low center moved northeastward and a large continental polar or continental arctic high pressure area from Canada moved in behind the front, bringing northwest winds to Philadelphia. In general, there was some precipitation in Philadelphia with

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(1) This section has been prepared by Gary A. Yoshioka, Geography Department, Johns Hopkins University, who has served as a Research Assistant on the contract.

(2) A paper by F. K. Davis and H. Newstein entitled "Meteorological Analysis of the November, 1966 and January, 1967 Air Pollution Episodes in Philadelphia" is included in Appendix A. A description of the general circulation and weather during a particularly long period of smog in 1953 is given in Appendix B. This condition has occurred several times in the last decade accompanied by poor air quality.

the passing of the front, and there were large areas of precipitation to the north and west. Soiling index values remained low as long as the low pressure center to the northeast and the high to the west produced a strong pressure gradient over the Philadelphia area.

The 500-millibar map showed a trough of low pressure over the study area from a center over Quebec or northern New England. The trough moved eastward during the period with a ridge of high pressure pushing eastward from the vicinity of the Gulf of Mexico. The upper-air winds were generally strong (40-60 kts) and shifted from southwesterly to northwesterly as the trough moved eastward.

Three exceptions to this generalized circulation pattern during periods of low soiling index occurred on October 1, October 22, and December 20. The October 1 pattern was similar to the general case with a cold frontal passage and a low in southeastern Canada; however, instead of a strong continental polar high from Canada moving into the Philadelphia area, a fairly weak ridge of high pressure extended eastward from a center in the Great Basin area. There was precipitation over the entire eastern half of the country. The 500-millibar map showed a ridge of high pressure over the east coast and a trough of low pressure extending southward through central United States with southwesterly winds over Philadelphia.

The October 22 surface weather map showed a large, diffuse low pressure area centered over the Middle Atlantic states which drifted northeastward and gradually merged with an intense low moving southeastward over southern Hudson Bay. There was a weak high over eastern Quebec and one over the Rocky Mountains. Winds over Philadelphia were generally northerly to westerly but not particularly strong. No significant continental polar air mass existed in the area. Large areas of precipitation covered much of eastern United States. On the upper-air map a deep low center moved up the Ohio Valley causing southwesterly winds over Philadelphia. A high center was found over the Great Basin area rather than over the Gulf of Mexico as is the normal case.

On December 20, an intense low off the Newfoundland coast moved northward, and a weak continental polar high moved across the Great Lakes to New York. There was a family of weak lows in the Atlantic and a weak low over Wisconsin. Precipitation fell to the north and west of Philadelphia. This pattern was so unlike those previously studied that one had to conclude that the low values of soiling index resulted more from reduced pollution activity due to the Christmas season than to meteorological conditions. The situation was not considered particularly representative.

The eight events which are described by the general pattern, as well as the exception, were selected as low pollution periods on the basis of average daily soiling index records. If concentrations of suspended particulates, NO_2, and SO_2 are included as air pollution indices, only one event (July 19-20) meets all four low pollution criteria and only five periods (August 9, September 13, October 4-5, November 29, and December 20) qualify as low pollution periods with three of the four pollution indices.

The July 19-20 and November 29 events are among the eight which fit the general pattern for low pollution. The October 4-5 event, which did not meet the low soiling index criterion, also fits the general pattern. During the August 9 and September 13 periods, the Philadelphia area was influenced by the passage of a weak low pressure system to the north, but the weather pattern did not resemble the general case. These two periods, like those of October 1 and October 22, were characterized by widespread and heavy precipitation (.45" or more in Philadelphia).

Of the 13 below normal pollution periods which Davis (1960) reported for 1957-1959, six appeared to fit the general pattern described previously for similar 1965 events. Most of the remaining periods were similar in one respect or another to the general pattern, e.g. cold front passage or a strong low center in southeastern Canada.

b) High Pollution Levels

The fifteen periods of much above normal soiling index, unlike the much below normal cases, had no general pattern into which the majority of cases could be grouped. There were, however, certain consistent features in several of the periods. In seven of the cases, for example, the surface weather map showed a large high pressure area which moved slowly off the southeast coast of the United States, two of the other cases had a stagnant high over the Middle Atlantic states, and the remaining six events were marked by one high pressure system replacing another after the passage of a very weak front. Nearly all the periods had light surface and upper-air winds.

The seven events which were characterized by a high moving off the southeast coast all coincided with southwesterly surface winds over Philadelphia. The air mass itself was originally continental polar, but by the time of maximum pollution, maritime tropical air had fairly well replaced the polar air since the Delaware Valley area was generally on the back side of the high. Precipitation, if any, remained to the north of Philadelphia or arrived in the city near the end of the high pollution period. Upper air winds were relatively light. In some cases a secondary high center was located in the vicinity of Florida or Cuba.

On October 18-21 and March 2-4 a stagnant high pressure area remained over the Middle Atlantic States. Surface winds were light and variable, and there was no precipitation in the Philadelphia area. On the 500-millibar map winds were also light; there was a ridge of high pressure over the Delaware Valley area and low pressure troughs to the northeast and southwest of the Middle Atlantic states.

The other six high pollution periods had less in common. All experienced the passage of a weak front sometime during the period. The Philadelphia area remained under the influence of high pressure for most of the period. Characteristically, surface winds were light and there was often little or no precipitation in Philadelphia itself.

One unusual case, included among the last six, occurred on November 21-22. During this period a weak low center moved off the coast of Virginia and brought significant amounts of rain to the Philadelphia area. The fact that high pollution was recorded on these days, despite the meteorological situation, suggests that factors not apparent on the weather map may have been responsible for the high pollution level.

Considering the suspended particulate, NO_2, and SO_2 concentrations in addition to the soiling index criterion, we find that of the seven days during which high concentrations were reported for all indices, four days (March 3-4 and October 20-21) were in the stagnant-high-over-Philadelphia category. Two events (September 29 and November 6-7) had high concentrations of suspended particulates, NO_2, and SO_2 but were not previously considered among high pollution cases. These two periods had generally high pressure over Philadelphia, little or no precipitation in the area, with light surface and upper-air winds.

c) Conclusions

A study of synoptic weather conditions and significantly high and low air pollution levels in Philadelphia during 1965 indicates that the majority of low pollution events are associated with significant precipitation in the area, fairly strong northwest winds, and polar continental air. Most often a three- or four-day event is initiated by the passage of a cold front with a deep low center to the north of Philadelphia. This is followed by fresh northwest winds accompanying a mass of polar continental air. Low pollution levels remain as long as this northwesterly flow continues over Philadelphia.

High pollution levels do not seem to be as closely related to well defined synoptic situations. In general the Philadelphia area is influenced by a high pressure system with light winds and little or no precipitation. High pollution is most persistent when the high pressure center remains stagnant over Philadelphia for several days or moves slowly to the south or southeast of Philadelphia. Thus, although the weather patterns associated with high pollution levels are varied, there is a definite contrast between these patterns and those associated with low pollution levels. This contrast serves to emphasize the relationship between air pollution and weather conditions.

Is the relation between the general circulation or the synoptic meteorological situation as found on the weather map and air quality close enough to allow forecasts of air quality to be made a day or so in advance? The answer to this must be a qualified no. There are clearly certain weather situations in which a forecaster can be relatively certain that higher or lower pollution levels will develop. Such forecasts are relatively straightforward. The real problem results from the great majority of cases in which some question exists in the forecaster's mind concerning tomorrow's weather. Not only does the forecaster have to predict tomorrow's weather accurately but he also has to be willing to state what the relation between the synoptic situation and air quality will be tomorrow. Even with 100 percent accuracy in the weather forecast, he may still be wrong on the pollution level since many other factors still influence the relation between air quality and the synoptic weather pattern.

While it is clear that very high levels of air pollution will not occur with strong northwesterly winds accompanying a polar continental outbreak, there are a number of other meteorological situations which will also result in lowered pollution levels. Thus certain meteorological situations can be identified which should give significantly improved air quality, but not all times when it occurs can be so identified in advance.

Similarly, there are many different synoptic situations during which increased air pollution can occur. While these situations involve light winds, slow moving pressure systems, and generally high pressure, there are enough times when similar synoptic situations are found without high pollution to make it extremely difficult to forecast periods of high atmospheric pollution from the synoptic weather map alone. While current research efforts may, in the future, permit us to predict periods of high pollution well in advance, present techniques are not well enough advanced to permit control officers to issue plant close down orders a day in advance (before any significant levels of pollution begin to develop) with any real degree of confidence.

Air Quality During 1967

It is extremely difficult to obtain records of air quality for the current year because of the time required to analyze and assemble the data from many different sources. During the course of the present research study, four AISI smoke samplers[1] and four high volume air samplers[2] were obtained on lease and installed at selected sites in a north-south line from the WFIL-KYW tower in northwestern Philadelphia to the C.W. Thornthwaite Associates site in Centerton, New Jersey. Intermediate locations for samplers were at Drexel Institute at 32nd and Chestnut Streets in Philadelphia and at the offices of the Lewis Barton Company in Haddonfield, New Jersey.

Some difficulty was experienced in getting these samplers operative, in keeping the samplers in continuous operation, in maintaining the calibration of the instruments, and in keeping the instruments serviced. The records cover only the first ten months of 1967 and even here some gaps occurred because of operating difficulties.

Average daily values of soiling index from the AISI samplers, observing on a two-hour interval, have been obtained from the four stations. The daily and seasonal course of the results from three stations are given in figure 24. They are plotted in the same manner as the soiling index values for 1965 for the three Philadelphia stations for comparison purposes.

The three stations for 1967 are outside the downtown urban area. The WFIL-KYW tower at City Line Avenue in Philadelphia is surrounded by suburban development but it is definitely not an interior city location as are the three Philadelphia sampling sites for 1965. Haddonfield is a suburban community, and the environmental situation is quite similar to that around WFIL-KYW. Centerton is essentially a rural environment with only a handful of houses located within half a mile of the site. Open cultivated fields exist to the north and east of the site and extensive woodlands and a lake to the south and west.

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[1] Model F2 AISI Smoke Sampler, Cat. No. 2303, Research Appliance Corporation, Allison Park, Pa.

[2] Model 2000 High Volume Sampler, General Metal Works Company, Cleves, Ohio.

The traces of soiling index reveal clearly the environmental situation in the vicinity of the sampling sites. Values of soiling index are higher in the winter then the summer season of the year and the day-to-day variations in soiling index are greater in winter than in summer at all sites. This pattern is entirely consistent with the 1965 results from the three Philadelphia city stations.

The magnitude of the soiling index is, however, much less at the suburban and rural stations than at the city stations as would be expected. Centerton, New Jersey, especially shows only small day-to-day fluctuations in the period May, June, and July, with slightly greater fluctuations developing in August and September. Largest fluctuations were found in January and February but even these (except for one observation on January 4 which is suspect) are quite small. A value less than .25 COH units/1000 ft/day is found at Centerton on 198 days out of the 283 days of observations or 70 percent of the time. In contrast to this, less than .25 COH units/1000 ft/day is found at Haddonfield just 33 percent of the time and at 1501 Lycoming Street, Philadelphia (1965) less than 1 percent of the time. Even in the highly industrialized and urbanized Delaware Valley, the concept of relatively unpolluted air is not entirely an anachronism.

High volume air samplers were operated at three of the four sites at which we had AISI samplers (WFIL-KYW tower, Drexel, and Centerton). The Centerton sampler was operated on a fixed schedule of twice a week (Monday and Thursday) in an effort to obtain a sample of fairly average conditions (Monday) and possibly the worst conditions (Thursday). The results of the sampling program are given in table 24. The table shows values of suspended particulates ranging from a high of 135 $\mu g/m^3$ on Thursday, October 26, to a low of 22 $\mu g/m^3$ on Thursday, August 24. These values agree quite well with the 1965 record from nearby Bridgeton (table 19). There are actually little difference between the Monday and Thursday readings with an average suspended particulate concentration of 55 $\mu g/m^3$ found on Monday and 62 $\mu g/m^3$ on Thursday.

Bridgeton had an average annual value of 67 $\mu g/m^3$ based on 24 samples in 1965. The highest recorded value was 133 $\mu g/m^3$ and the lowest was 33 $\mu g/m^3$. The average at Centerton, 8 miles north of Bridgeton, based on 55 samples was 59 $\mu g/m^3$. There appears to be only a minor difference in suspended particulate concentration between Bridgeton and Centerton. The results indicate that there is apparently little difference between values obtained in the country and in essentially non-industrialized towns (population of Bridgeton approximately 20,000). The records of soiling index and suspended particulate concentration from places like Centerton and Bridgeton, when compared with similar records from Philadelphia and Wilmington, emphasize the significant differences in air quality that can exist. While it never will be possible to achieve country air in a city environment because of the nature of the city itself, the records from the more rural areas surrounding the metropolitan complexes provide goals at which to aim.

DAILY VARIATIONS IN SOILING INDEX AT THREE DELAWARE VALLEY STATIONS, 1967

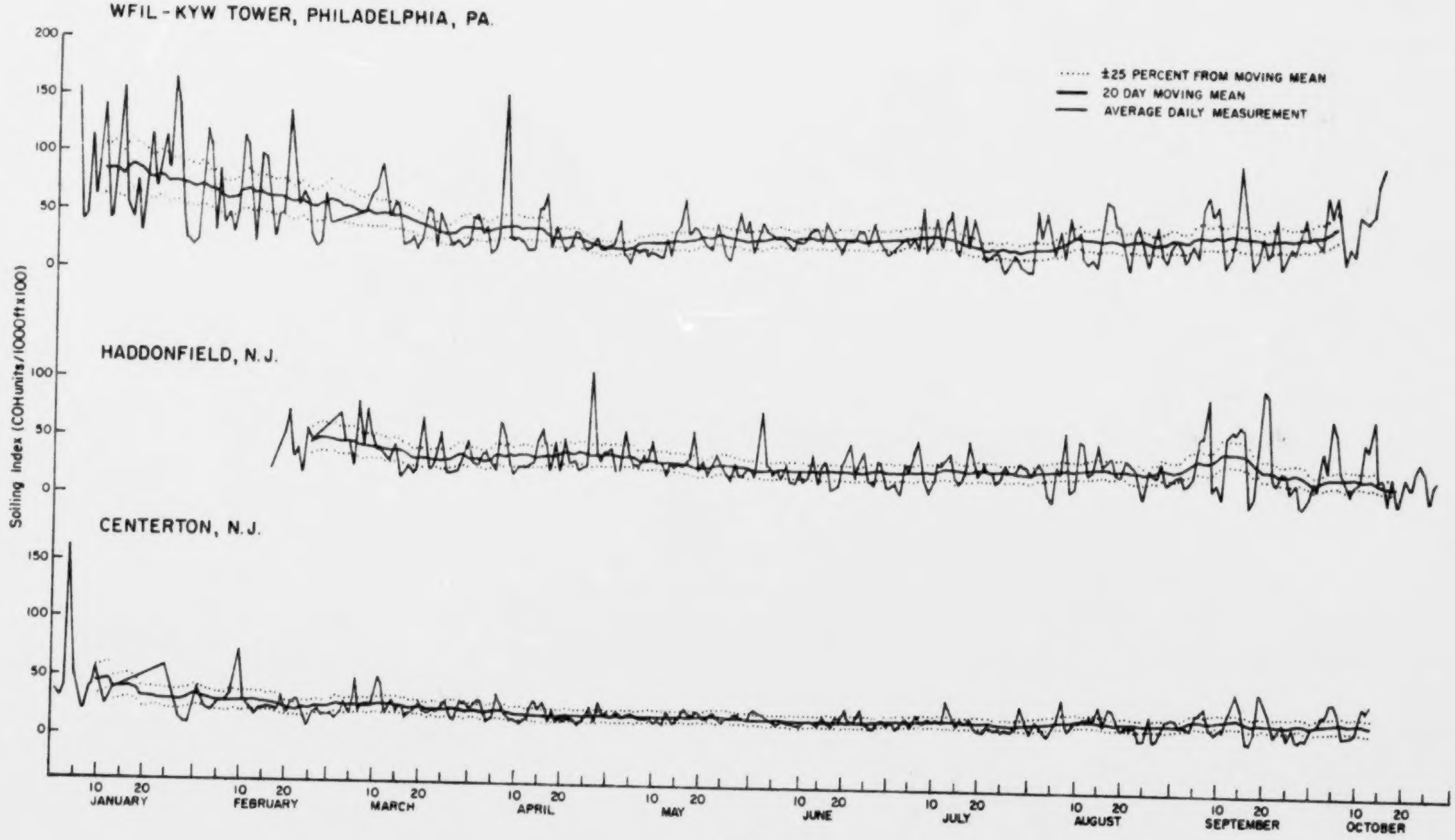

Figure 24

Table 24

Suspended Particulate Concentrations, Centerton, New Jersey 1967 (in μg/m^3)

Date	μg/m^3	Date	μg/m^3	Date	μg/m^3
3/28	56	6/ 1	69	8/28	72
3/30	47	6/12	56	8/31	59
4/ 3	38	6/15	104	9/ 7	61
4/ 6	72	6/19	48	9/11	26
4/10	42	6/22	56	9/14	86
4/13	65	6/26	64	9/18	91
4/17	42	6/29	53	9/21	38
4/20	50	7/ 3	132	9/25	54
4/24	36	7/ 6	73	9/28	45
4/27	46	7/10	36	10/ 2	64
5/ 1	53	7/13	91	10/ 5	74
5/ 4	45	7/17	112	10/ 9	50
5/ 8	40	8/ 3	31	10/12	66
5/11	65	8/ 7	46	10/16	39
5/15	58	8/14	74	10/19	36
5/18	68	8/17	73	10/23	33
5/22	36	8/21	40	10/26	135
5/25	40	8/24	22	10/30	66
5/29	49				

CHAPTER VI. CONCLUSIONS

The present study of meteorology and air pollution in the Delaware Valley has involved an investigation of a) the availability of data and the existing and needed observation network; b) the air flow over the basin area; c) the stability conditions (inversions and mean mixing depths) that would influence the rate of mixing of the air with elevation; d) the varying air quality over the basin as it is related to synoptic meteorologic conditions; e) the possibility of using meteorologic conditions to forecast limiting pollution episodes; and f) detailed interpretation of several specific high pollution events.

A great many conclusions are possible based on the study to date. It is quite clear that a one-year study does not provide sufficient time for study of all aspects of the problem, but the preliminary conclusions seem fully justified on the basis of the available information.

A) Meteorologic Data and Observation Network

1. Reliable wind observation stations are not well distributed over the 11-county area. A large number are in the immediate Philadelphia area, but there are only a few in the western, northwestern, and southeastern parts of the area. Additional wind recording stations in Chester, Bucks, Salem, Gloucester, and Camden counties would be very helpful in meteorological analyses.

2. A number of wind observing stations provide records of only limited usefulness because of problems of exposure, calibration, or reliability of the sensors and recording systems. Great care must be taken in evaluating all records of wind in an effort to recognize probable errors and to eliminate them.

3. Stations recording meteorological data should be set up and operated by individuals who have had some meteorological background or training in order to provide the most reliable and useful results. If this is not possible, it might be preferable to forego the observing program rather than to collect incorrect observations.

4. Two stations recording the vertical profile of wind and temperature (only one above 300 ft) are not sufficient to provide a good understanding of the vertical distribution of these important meteorological factors over the area. The excellent vertical profile of temperature from the WFIL-KYW tower is influenced by its city location and one or two additional tower stations would be most desirable to provide a more complete meteorological analysis.

5. Stations measuring suspended particulates are well distributed, but the relatively few observations per year limit the usefulness of the data. On certain selected days, similar observations should be taken at all stations in the area to allow the synoptic pattern of air quality to be determined.

6. Other factors of air quality, in addition to suspended particulates, must be measured on a fairly routine basis at more places in the area. While additional CAMP (Continuous Air Monitoring Program) stations would be desirable, it might not be necessary to have such a complete observing program at other stations. Two or three additional stations giving daily values of sulfur dioxide, nitrogen oxide, carbon monoxide, and suspended particulates would be most helpful in any further air pollution analysis.

7. Vertical profiles of air quality would be desirable to have. The few available observations from the WFIL-KYW tower and from other study areas indicate a significant change in air quality with height. These changes should be better documented with a year or more of daily data.

B) Air Flow over the Basin

1. The concept of an airshed or air basin has no real significance in the Delaware Valley area. The eastern seaboard from the coast westward to the Appalachian-Allegheny ridges and running north-south from at least Virginia to Massachusetts has to be considered as one continuous atmospheric area. Restricted river valleys or other isolated basins in the area are not airsheds and result in only localized eddies in the general air flow.

2. No portion of the basin area seems more prone to lowered air quality than any other on the basis of meteorologic and topographic conditions, although the distribution of pollution sources does result in certain localized regions of higher pollution.

3. Late summer and early fall are the most favored times for long consecutive periods of light winds of importance in increasing pollution hazard.

4. Prevailing winds over the basin are north of west in the winter season and south of west in the summer season. Wind velocities are higher in the winter than in the summer.

5. Wind roses prepared for periods of high and low air pollution reveal marked differences.

   a) Low pollution conditions are associated with strong winds predominantly from the northwest while high pollution conditions are much more frequently associated with low wind speeds or calms and southwest winds.

6. Wind roses during times of temperature inversions revealed no significant differences from wind roses prepared from all available wind data. Circulation conditions at times of inversion are not unlike circulation conditions at other times.

C) Stability of the Air

1. Inversions of air temperature are found in all seasons of the year with the peak number in the summer months (June-September). The summer period is also the favored time for more persistent inversions to occur (inversions lasting for several days).

2. Maximum mixing depths are lowest and low mixing depths are most persistent in December and January although the greatest frequency of reasonably low maximum mixing depth (without regard for duration of the event) is in the summer and fall period.

3. The occurrence of low afternoon mixing depths which reach a maximum in December, January, and February seem to be related to air quality. When low values of mixing depth occur in the afternoon, there is a good possibility that they will also occur in the early morning as well. Thus, low afternoon mixing depths reflect the possibility of stable conditions existing for 24 or more hours.

D) Air Quality

1. Peak values of different air pollutants do not occur at the same time suggesting that different environmental and meteorological conditions are responsible for their concentration in a particular area.

2. There is an above average level of pollution over the Delaware Valley area as a result of the heavy concentration of people and industry although only Philadelphia, Bethlehem, and Wilmington have suspended particulate concentrations above the national average for urban areas.

3. Soiling index, suspended particulate concentration, carbon monoxide, nitric oxide, and sulfur dioxide all experience higher values in the fall and winter periods of the year and lower values in the summer months. Nitrogen dioxide, total hydrocarbons, and total oxidants appear to experience higher values in the spring and summer months and lower values in the fall and winter season based on 1965 data.

4. Highest values of pollution in the valley area are found in Philadelphia with a fairly narrow band of high values of suspended particulate concentration running northeast-southwest along the highly industrialized river valley from Wilmington to Trenton. This band does not extend to any great degree to the northwest or southeast indicating relatively limited movement of suspended particulates.

5. Day to day variations in suspended particulate concentrations are much greater in winter than in summer although appreciable variations occur in all seasons of the year. Periods with two or more consecutive days with values of suspended particulates well above or below the 20-day moving mean are fairly evenly distributed through the year with a few more periods in winter than in summer.

6. Daily values of suspended particulate concentration in the urban area are highest on Thursday and lowest on Sunday reflecting the weekly industrial and automobile activity. In suburban and rural areas, the weekly variation is much less noticeable with five different days having essentially the same values. A strong weekly bias would not be expected since these areas would not experience any strong weekly variation in industrial and automobile activity.

E) Forecasting Pollution Events from Meteorological Conditions

1. Detailed study of periods of much above and below normal pollution reveals:

    a) The majority of the low pollution periods are associated with significant precipitation, fairly strong northwest winds, and a polar continental air mass moving over the area from Canada. Most often the low pollution episode is initiated by the passage of a cold front with a deep low pressure center north of the area. The high pressure that pushes in behind the front brings cold, clear, northwest winds. Low pollution levels remain as long as the northwesterly flow continues.

    b) High pollution levels are not as clearly related to particular circulation patterns. With high pollution, the area is covered by a weak high pressure area, with light winds, and little or no precipitation. The high pressure area remains stagnant over the area for several days or moves slowly to the southeast. Winds are generally from the southwest on the back side of the high pressure area.

2. Many different synoptic meteorologic situations exist during which increased air pollution occurs over the Delaware Valley. There are enough differences in these situations, or there are enough times when similar meteorologic situations are found without high pollution, to make it extremely difficult to forecast periods of high atmospheric pollution from the weather conditions alone.

3. The importance of non-meteorologic as well as meteorologic factors in air pollution makes it extremely difficult to forecast air quality from meteorologic factors by themselves.

F) Detailed Case Studies of High Pollution Episodes

1. Even during extended periods of high atmospheric pollution (November 21-26, 1966, January 23-27, 1967) it is not necessary for inversion conditions to exist near the ground at all times. Unstable atmospheric conditions were observed for short periods in the middle of each day of the high pollution period.

2. The top of the inversion layer is around 350 ft in Philadelphia although the lapse rate above is nearly isothermal up to the top of the tower observations (890 ft).

3. Most obvious characteristic of the wind field during a serious pollution episode is persistently low winds. Wind speeds at 40 ft practically never exceed 4 knots.

4. Highest air pollution levels are not strongly correlated with greatest inversions, nor are they consistently related to periods of lowest wind speeds. Peak pollution values at ground level are measured within a few hours after sunrise and may be largely a result of the fumigation process (downward transport during period of inversion breakup from below).

    a) Highest concentrations of sulfur dioxide were found aloft but below 500 ft (possibly near 350 ft). By inference, sulfur dioxide concentrations aloft over downtown Philadelphia may reach levels well above 1 ppm during a severe air pollution episode.

5. Two hundred-foot towers are not sufficiently high to record some air pollution and meteorological data of significance for analysis.

G) General Conclusions

1. More important than the occurrence of any particular meteorological event is the duration of the limiting meteorological condition coupled with the nonmeteorologic conditions of availability of pollutants. While the duration of limiting meteorological events may appear to be more favorable for pollution episodes in late summer and fall, it is only in the winter that meteorologic conditions combine with the abundance of pollution material to produce the most serious episodes of pollution in the Philadelphia area. Thus any study of air pollution must be concerned with the seasonal occurrence of both meteorological conditions and atmospheric pollutants since serious pollution episodes result from the juxtaposition of both limiting factors.

2. The importance of non-meteorologic as well as meteorologic factors in air pollution makes it extremely difficult to forecast air quality from a knowledge of meteorologic factors or the weather map alone. The importance of non-meteorologic factors, which can

be manipulated or controlled, as opposed to the meteorologic factors, which can only be understood but not controlled, indicates the important role that planners and other physical and social scientists must play in air pollution abatement.

3. A study of air quality in the highly industrialized Delaware Valley area suggests a condition of serious but not extreme conditions for any of the atmospheric pollutants. The potential for very serious pollution certainly exists. It is probably only because of our relatively favorable meteorologic situation, with few stagnant highs and persistent inversions, and our favorable topographic situation, with little opportunity for air to become trapped in valleys or basins, that more serious pollution episodes do not develop.

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APPENDIX A

Paper No. 67-179

METEOROLOGICAL ANALYSIS OF THE NOVEMBER, 1966 AND JANUARY, 1967 AIR POLLUTION EPISODES IN PHILADELPHIA*

by

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and

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Abstract

Continuous meteorological observations have been made during the past two years on a 1000-foot tower in Philadelphia. An analysis is presented here of the general weather patterns, the vertical temperature structure and the wind conditions associated with two periods of high air pollution concentrations in Philadelphia.

Measurements of the vertical distribution of pollutants and their variations are presented for the second period.

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The results of this study have direct applicability to the current investigation. Dr. Newstein is a consultant on the present RCEO investigation. Rather than having him prepare a separate paper on this same subject, this report by Davis and Newstein is reproduced here in full with the kind permission of the authors. The paper was presented at the National Conference on Air Pollution in Cleveland, Ohio in June, 1967 and has been submitted for possible publication in the Journal of the Air Pollution Control Association.

I. Relation of Meteorological Conditions to High Pollution Levels in Philadelphia

Relating meteorological parameters to air pollution concentrations in a given city is not a simple task. Although most large cities across the nation make air pollution measurements, there are still no fixed standards for types of measuring instruments, for location or height of exposure of instruments, or for the atmospheric conditions under which such measurements are made.

In the meteorological department, wind speed and direction measurements are often available consistently only at U. S. Weather Bureau Stations with the instruments exposed at relatively high levels and at airports located at some distance from the urban areas they represent. Furthermore, in most cities no vertical temperature measurements are available, and atmospheric stability must be inferred by methods such as those employed by Turner[1] in his Nashville study. Observations by DeMarrais[2] and Davidson[3] show that stability conditions over an urban complex are quite different from those over open areas.

The study presently being conducted by Davidson[3] and his group in New York is an attempt to provide meteorological and air pollution measurements in greater quantity and in more appropriate forms to more clearly define the relationships between the two. Meanwhile, attempts have been made to analyze available observations to gain a greater understanding of the air pollution problem in a particular city.

Davis[4] analyzed 10 years of weather data and 3 years of air pollution data for Philadelphia in an effort to relate general weather patterns to periods of high air pollution levels. Some consistent weather characteristics were evident to the extent that Davis[5] was able to demonstrate some success in forecasting high air pollution levels in Philadelphia on the basis of forecasting weather conditions.

These studies indicate that the general weather patterns associated with high air pollution levels in Philadelphia develop as follows. A continental polar high pressure center moves out of Canada across the Great Lakes and off the east coast. This high becomes stationary, or very slow moving, at or near the coast, and the Philadelphia area is influenced by very light winds between west and south for several days, with southwest flow heavily predominant. Wind speeds are generally less than 8 mph for periods of many hours.

II. General Weather Patterns for the Two High Pollution Periods

The two most recent periods of very high air pollution levels in Philadelphia occurred November 21 into 26, 1966 and January 23 into 27, 1967. These 'episodes' actually covered the entire northeast and mideast coastal area. In the November case, New York City's commissioner of air pollution control, Austin N. Heller, said it may have been the city's highest air pollution level in history. Dr. Ingraham, Philadelphia's Health Commissioner, said the situation posed a "serious potential danger to public health" and called on seven large coal and oil burning industries to cut back on fuel consumption.

The weather patterns for these two situations were similar to those generally associated with high air pollution levels in Philadelphia, and might well have been forecast.

In the first case, early on November 20th a large high pressure center transporting continental polar air stagnated over New York, resulting in light north to northeast winds along the Atlantic coastal area. It showed little or no movement during the next 24 hours, then drifted slowly eastward, stretching from Maine to North Carolina on the 22nd and 23rd of November. The center was placed over Virginia and the Carolinas on the 24th of November and over Alabama and Georgia on the 25th. Throughout the entire period winds were very light, predominantly less than 8 knots from the 22nd through the 25th.

The second case was similar to the first. A high pressure center transporting continental polar air moved over New York on January 19th, and drifted slowly southward where it stagnated right along the mideast coast on January 20th and remained almost stationary on or just off the coast of the Carolinas through the 25th. By midday on the 26th it had moved eastward to allow a cold front to bring a change of air mass to the Philadelphia region. From January 23rd through most of the 26th wind speeds were almost always 8 knots or lower, and in most instances were reported less than 5 knots at the airport station of the Weather Bureau.

III. Tower Instrumentation and Location

Continuous vertical soundings of the atmosphere are available for the first time for analysis in connection with high air pollution levels in Philadelphia. Through a United States Weather Bureau contract and with the permission of both stations and the active cooperation and participation of WFIL-TV, instruments have been installed on the 1000 foot WFIL-KYW TV tower which is located about 6½ miles NNW of Drexel Institute of Technology and 12 miles north of the U. S. Weather Bureau Station at the Philadelphia International Airport. This area is within the boundary of the City of Philadelphia and is of a general suburban nature. There are rolling hills with the ground elevation up to about 300 ft. above msl.

The installation consists of Bendix-Friez Aerovane wind instruments, Leeds & Northrup Thermohm resistance wire thermometers and Minneapolis Honeywell Lithium Chloride Dew Probes. Instruments are located at the ground and at levels of 40', 100', 200', 350', 570', and 890' above the ground. Anemometers are exposed 10' away from the tower structure and thermometers about 4' away.

The overall system includes the meteorological sensors on the tower and an instrument shelter at the ground all connected by cables to recorders in a building about 80 ft. from the base of the tower. In addition to the analog record thus produced continuously on individual strip chart recorders, an analog voltage for each of the sensed variables is automatically produced and converted to digital form by a precise and stable digital voltmeter. The digital information is then transmitted via Bell Telephone Company Data Phone system to Drexel Institute of Technology, a distance of about 6½ miles from the tower site, where IBM cards are punched automatically for each observation.

Complete details of the meteorological system and characteristics of the instruments are available in a report by Newstein[6].

Work has also been proceeding on plans to instrument the tower for continuous and automatic air pollution measurements, and the feasibility of that plan has been established. Some spot sampling has been carried out to observe the order of magnitude of concentrations and their vertical variability. Measurements of SO_2 concentrations were scheduled during the January "episode".

For SO_2 measurements the Gelman sequential bubbler sampler was modified so that it could be installed on the tower and operated with a minimum of attention. The basic changes are: (1) The single box arrangement was changed to two packages: one, the power module which contains the controlling clock and blower; the other, the sampler module which contains the sequential valve and the bubblers. (2) In place of the flow meter a calibrated limiting orifice is used to control the air flow rate. (3) Heaters were installed at appropriate locations to prevent the reagents from freezing, to prevent condensation from interfering with the flow rate, and to prevent the pump from freezing. (4) The boxes are mounted in such a manner that one person can conveniently remove the sampler module and replace it with another that has previously been prepared in the Laboratory. (5) Power is secured from each of the meteorological sensor levels. Necessary fuses and safety interlocks have been provided.

These sequential bubbler samplers are mounted at the ground near the meteorological instrument shelter and on the tower at the 100 ft., 350 ft., and 570 ft. levels. The sampling is for concentrations of SO_2 and the method of analysis is the modified West-Gaeke method.

Air pollution data in Philadelphia for the two smog periods are available from about six locations, but for purposes of relating air pollution levels to meteorological conditions in this study, the sulfur dioxide concentrations obtained at the CAMP station are used as a pollution indicator. These are measured at 20th and Race Streets in downtown Philadelphia by the electrical conductivity method.

IV. The Vertical Temperature Structure in the November Episode

The vertical temperature profiles during the high air pollution period in November show several characteristics of interest and significance. First of all, the temporal changes in the lapse rates followed what might be called a "classical" pattern described in textbooks such as the one by Geiger[7]. Heating and cooling were initiated and propagated from ground level, forming strong temperature inversions beginning in the late afternoon and persisting until after sunrise. Figure 1 illustrates the temperature differences between the 890 ft. level and the ground level (5 ft.), and it is obvious that the cycle was consistent throughout the period.

Note that the temperature inversion did not persist through the day but that a superadiabatic lapse rate was observed for a short period each day in the middle of the day. Thus, it is not necessary for a low level temperature inversion to persist continuously for several days in order for pollution levels to build up to "episode" portions.

There appears to be a consistent dip in the curve within an hour or two of midnight, indicating a tendency toward somewhat less stable conditions. Examination of the hourly lapse rates shows this to be a result of a singular rise in ground level temperature alone. The reason for this is not immediately obvious, but the records show a slight increase in low level wind speeds coinciding with the ground level temperature rise. We have not had time to pursue this in detail, nor do we have any wind records below the 40 ft. level, but this seems to be an interesting micrometeorological phenomenon worthy of further investigation.

Figure 1 also shows the pattern for the temperature differences between the 890 ft. level and the 40 ft. level. It is essentially the same, but with a slight time lag and a smaller amplitude, as might be expected. Furthermore, the nighttime dip does not appear as indicated previously.

Another interesting feature of the vertical temperature structure is the fact that the top of the inversion layer is mostly at the 350 ft. level, though the lapse rate above is often nearly isothermal during periods of inversion below. This relationship is illustrated in Figure 2.

The typical "classical" diurnal variation of the lapse rate during this high pollution period is shown in Figure 3. This covers the period 0600 November 21 through 0400 November 22. It indicates that the heating extends upward from the ground level as superadiabatic lapse rates are set up in the lowest layers, and the low level inversion is entirely broken up before the entire layer is heated. This is in contrast to some observations presented by DeMarrais[8] which indicate heating to a great depth immediately after sunrise without breakup of the surface inversion. The less stable conditions around midnight between the ground and the 890 ft. level, as noted in Figure 1, are represented by the 2200 temperature profile shown in Figure 3(b).

V. The Vertical Wind Structure in the November Episode

The most obvious characteristic of the wind field is persistently low wind speeds during the high pollution period. The wind speed at the 40 ft. level practically never exceeded 4 knots, and at the 100 ft. level speeds were almost always 8 knots or lower. This can be seen in Figure 4 which shows wind speeds at various times and heights from November 20, 1966 through November 25, 1966.

A possible influence of the upward extension of the friction layer resulting from daytime heating is clearly evident. Wind speeds at the upper two levels show nighttime maxima and daytime minima. Isopleths of wind speeds in Figure 4 show uniformly low wind speeds extending upward from the 40 ft. level to the top of the tower during the 1000 to 1600 time periods. The wind shear has an obviously strong dependence on the temperature structure, with the exponent in a power law having larger values during stable periods at night and smaller values during the daytime periods of instability.

The tendency toward slightly higher low level wind speeds at times during the night, which might have been associated with enough mixing to produce

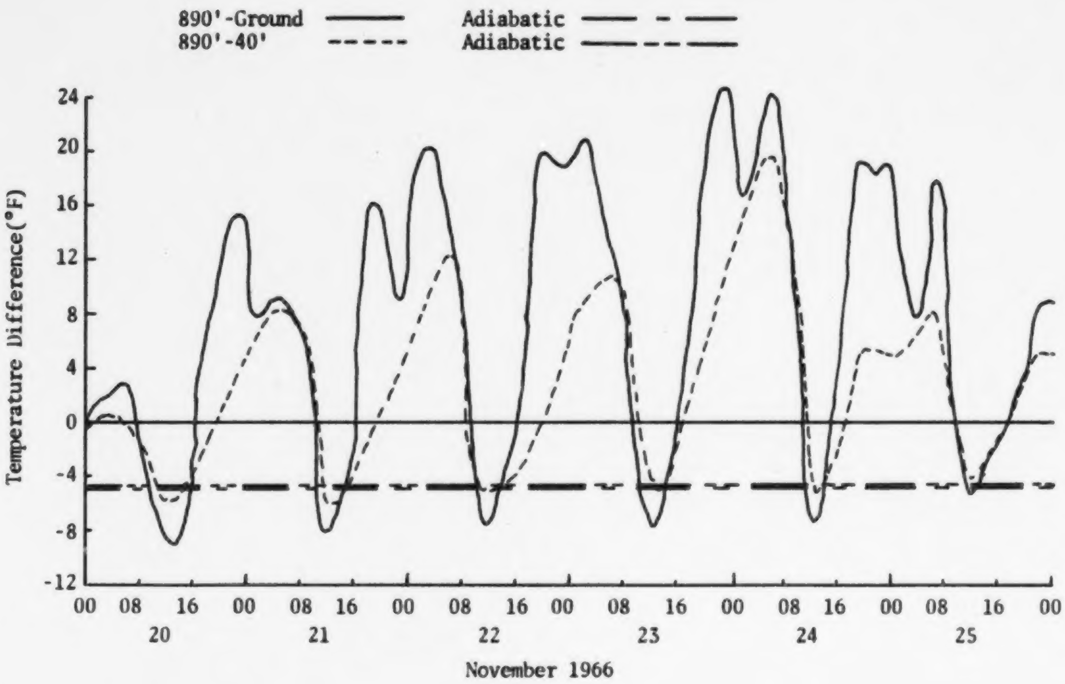


Figure 1. Temperature Differences Between the 890' and Ground Levels and Between the 890' and 40' Levels on the Philadelphia Tower

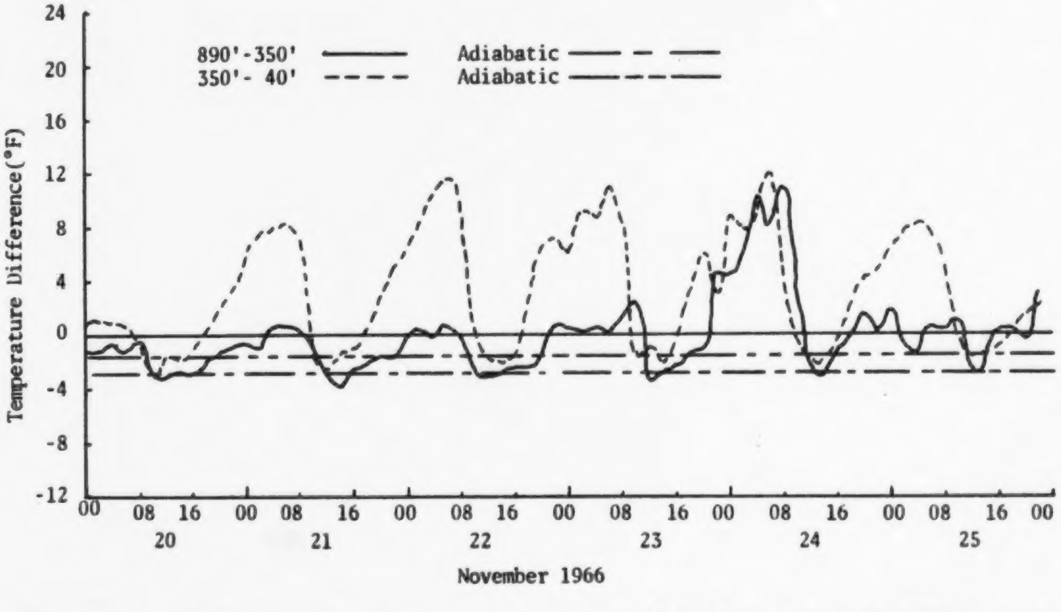
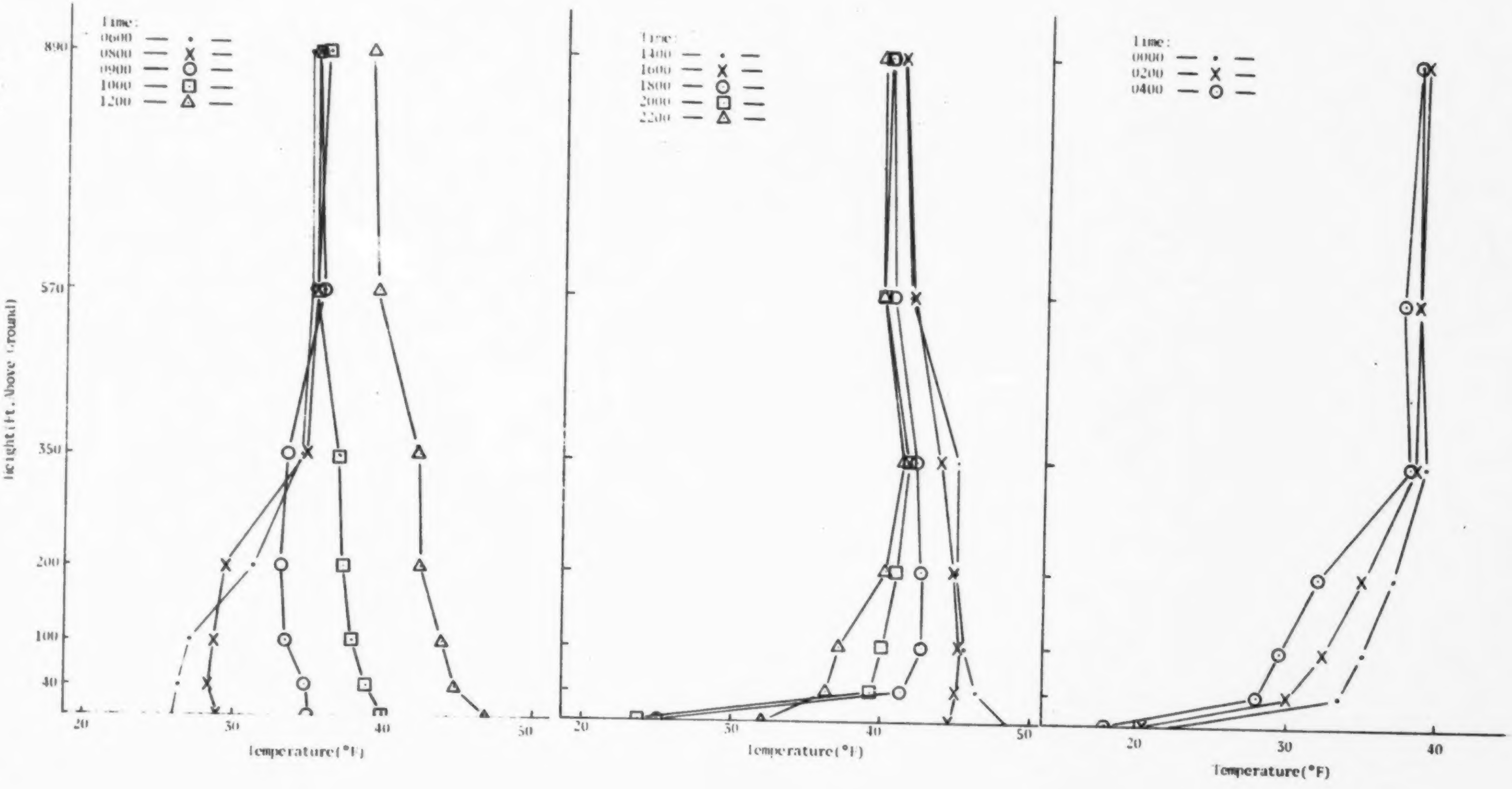


Figure 2. Temperature Differences Between the 890' and 350' Levels and Between the 350' and 40' Levels on the Philadelphia Tower



(a) Nov. 21, 1966

(b) Nov. 21, 1966

(c) Nov. 22, 1966

Figure 3. Variation of Temperature With Height and Time at the Philadelphia Tower: 1966

the higher ground level temperatures discussed in section IV, are not clearly defined in the gross analysis presented in Figure 4, but are indicated. It is probably necessary to look more closely at the wind structure below 40 ft.

VI. Air Pollution Levels in the November Episode

Measurements of air pollution concentrations of various pollutants at different locations in Philadelphia are available through the Philadelphia air monitoring program of the Department of Public Health. Sulfur dioxide concentrations are often used as an air pollution index, and Figure 5 shows hourly average values of the sulfur dioxide concentrations measured at the CAMP station in Philadelphia, located at 20th and Race Streets. Table 1 gives peak and average values during the November episode.

Table 1

Sulfur Dioxide Hourly Averages and Hourly Peaks
Philadelphia CAMP Station

Date	Average (ppm)	Peak (ppm)
11/20/66		0.26 (10-11 PM)
11/21/66	0.17	0.30 (7- 8 AM)
11/22/66	0.26	0.52 (9-10 AM)
11/23/66	0.26	0.50 (6- 7 AM)
11/24/66	0.11	0.24 (9-10 AM)
11/25/66	0.23	0.64 (8- 9 AM)
11/26/66	0.53	0.12 (Mid-1 AM)

Highest air pollution levels are not strongly correlated with greatest inversions, nor are they consistently related to periods of lowest wind speeds. In general, of course, conditions of low wind speed and temperature inversions are associated with the air pollution "episode" in November. On the other hand, Table 1 shows that peak pollution values at ground level were measured within a few hours after sunrise and may be largely a result of the fumigation process.

VII. The January, 1967 Episode

Figures 6 and 7 show that the vertical temperature structure during the January episode was essentially the same as that during the November period. The main difference, perhaps, is stability through a greater height in January and a somewhat less consistent interruption of the low level nighttime stability. Also the inversion generally extended up through the levels above 350 ft. in a much more definite manner.

The wind speed pattern is drawn in Figure 8 and reveals the same features as described in connection with the November episode. It shows the pronounced midday minima and nighttime maxima at the upper levels as well as wind speeds of predominantly 8 knots or less at the 100 ft. level and 4 knots or less at the 40 ft. level.

The sulfur dioxide concentrations measured at the CAMP station in Philadelphia are shown in Figure 9 and Table 2.

Table 2

Sulfur Dioxide Hourly Averages and Hourly Peaks
Philadelphia CAMP Station

Date	Average (ppm)	Peak (ppm)
1/23/67	0.32	0.56 (9-10 AM)
1/24/67	0.20	0.38 (7- 8 AM) (9-10 AM)
1/25/67	0.23	0.50 (11AM-12)
1/26/67	0.31	0.64 (2- 3 AM)
1/27/67	0.12	0.36 (8- 9 AM)

They are closely comparable to those measured in the November episode, even though the wind direction is significantly different. It is believed that the principal SO_2 sources are southwest of the CAMP station, so that measurements for the January period should have been higher if source strength were the principal factor since the wind direction was mostly from the southwest during that time.

During the January episode some measurements of sulfur dioxide concentrations were made on the tower so that a vertical distribution was obtained. The SO_2 concentrations measured were one and a half hour averages beginning at 12:30 P.M. on January 24 and continuing until noon on January 25. Figures 10 and 11 show the vertical profiles of temperature and sulfur dioxide over that period.

As the temperature inversion built up during the late afternoon and evening hours, sulfur dioxide concentrations increased first at levels above the ground. By 8 P.M. the ground level concentration had not changed appreciably, but the concentration at the 100 ft. level had increased 5 fold while that at the 350 ft. level had multiplied by 4. By two hours later the concentration at the 100 ft. level had further doubled, though it increased but slightly after that during the remainder of the night and through the following morning.

Meanwhile, the ground level concentrations increased much less during the night and reached a maximum at 10 A.M. when the inversion had been broken up in the lowest 100 ft. This indicates again the fumigation effect, or the mixing in the lower layers which brings down pollutants from above. By noon the sulfur dioxide showed the effect of mixing through a deeper layer.

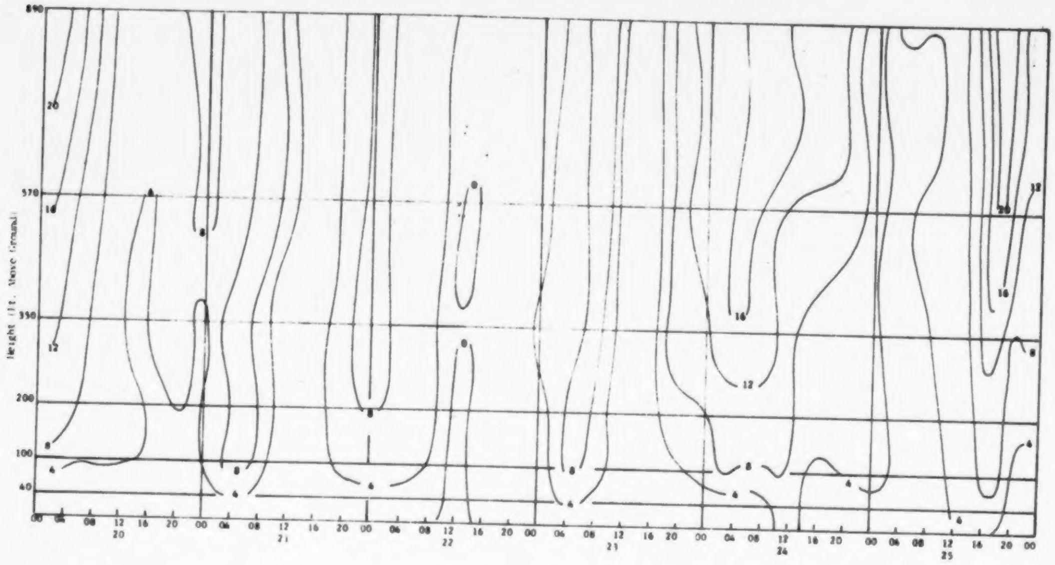


Figure 4. Variation of Wind Speeds With Height and Time at the Philadelphia Tower--November, 1966

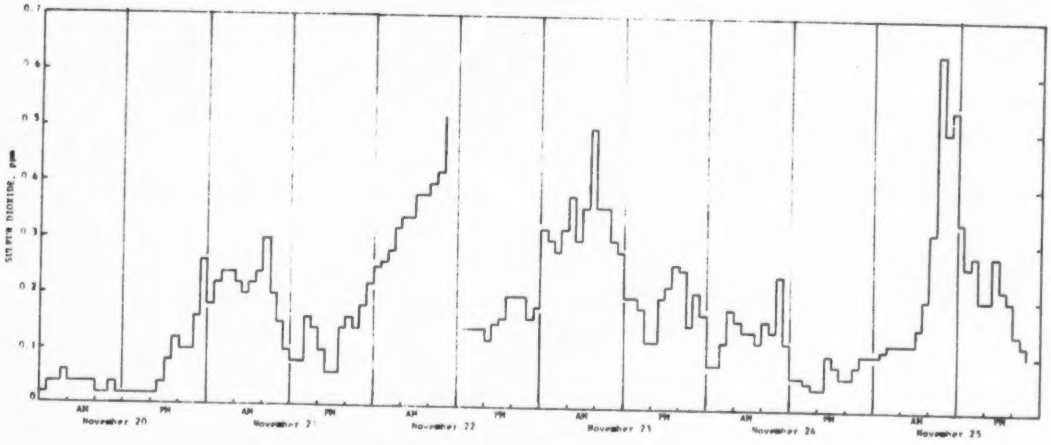


Figure 5. Sulfur Dioxide at 20th and Race Streets--1966

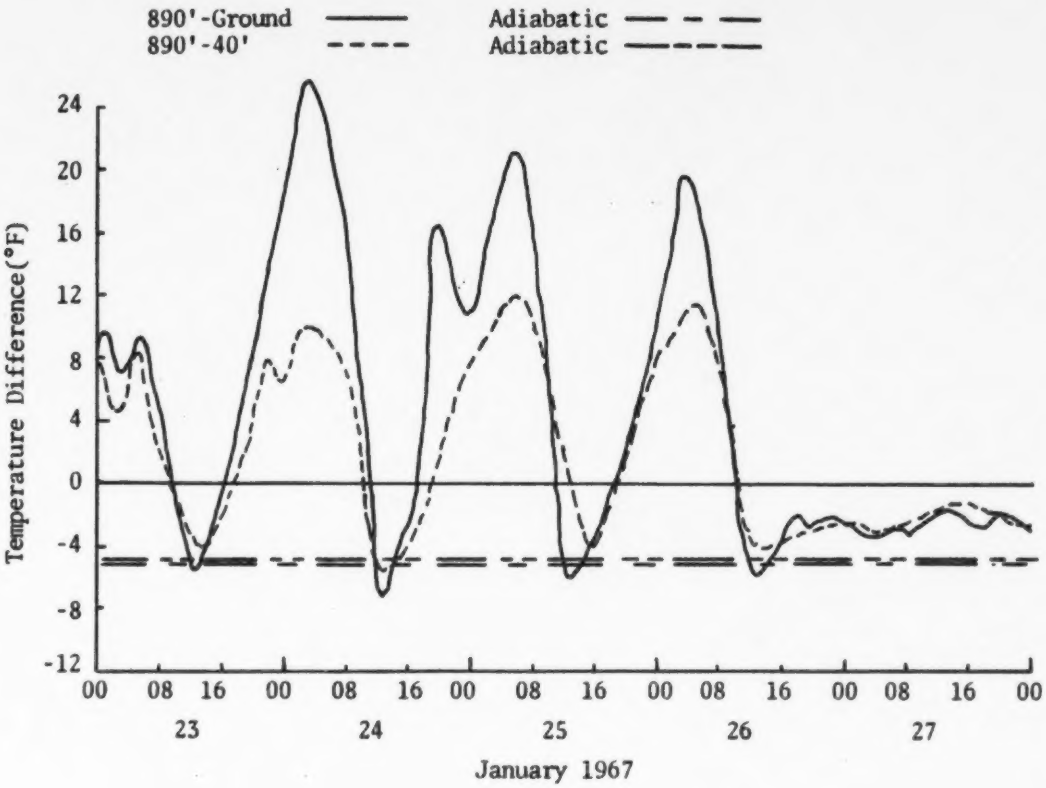


Figure 6. Temperature Differences Between the 890' and Ground Levels and Between the 890' and 40' Levels on the Philadelphia Tower

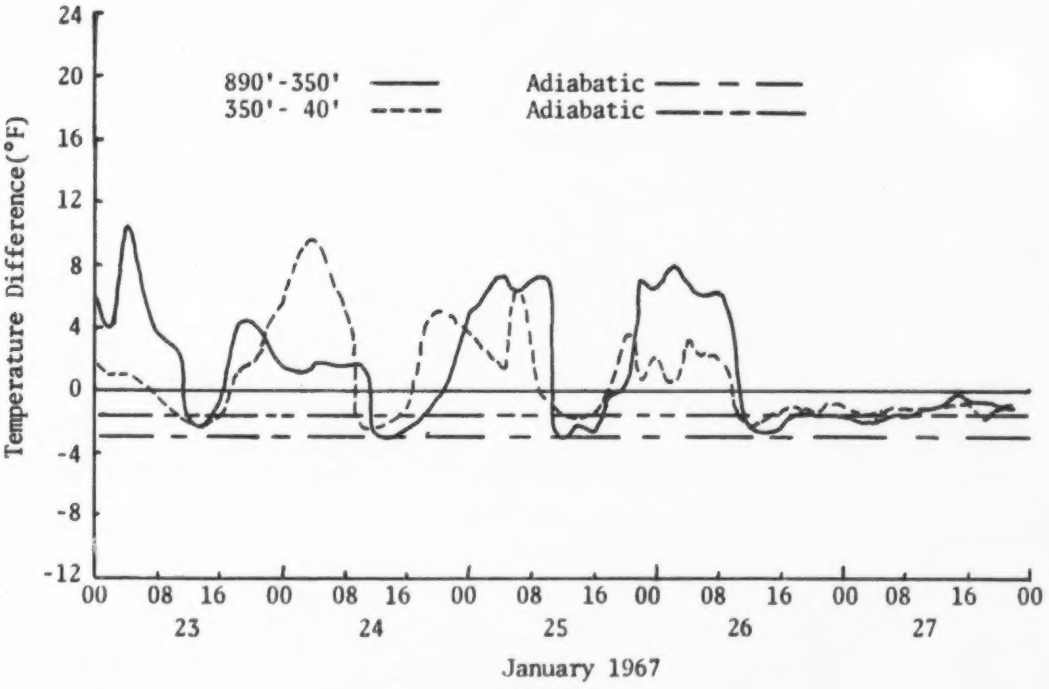


Figure 7. Temperature Differences Between the 890' and 350' Levels and Between the 350' and 40' Levels on the Philadelphia Tower

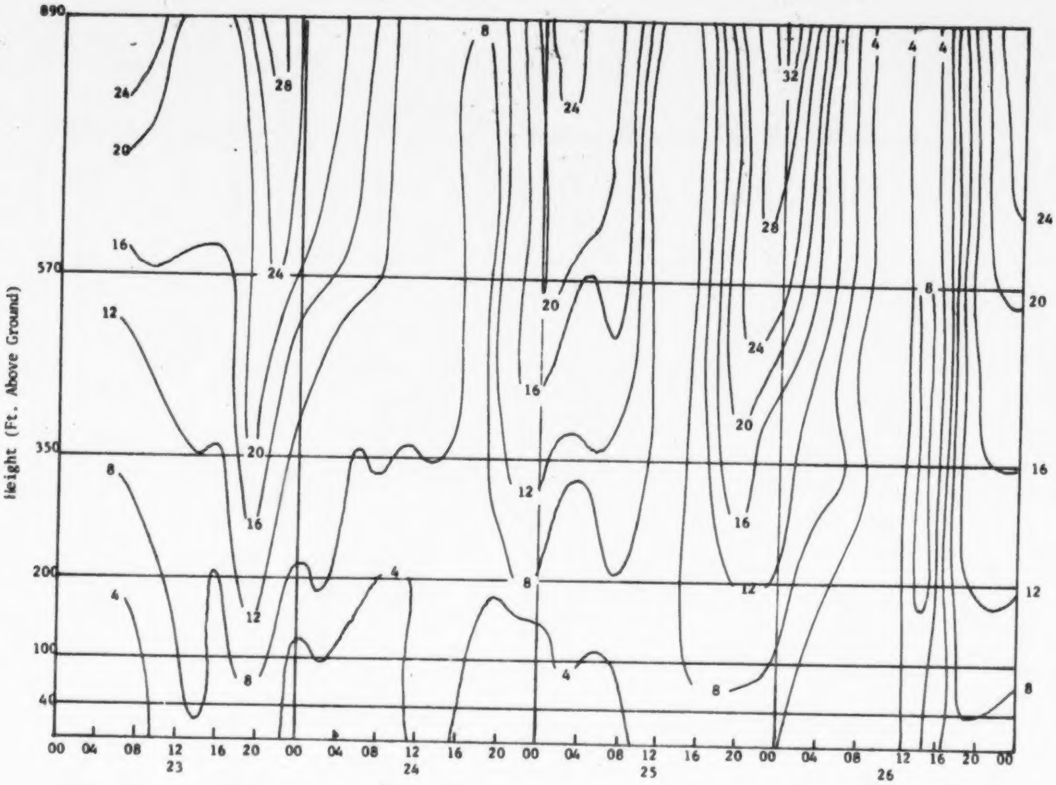


Figure 8. Variation of Wind Speeds With Height and Time at the Philadelphia Tower--January, 1967

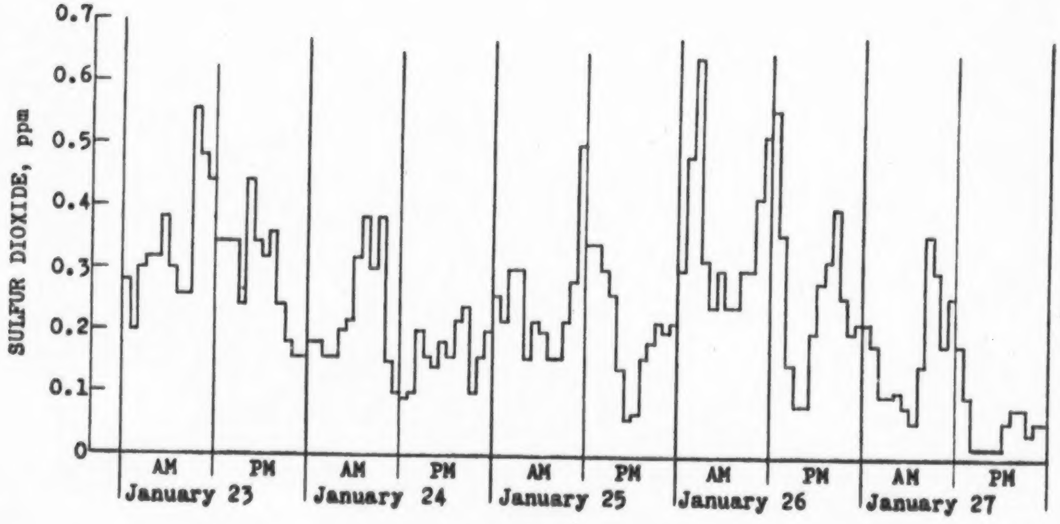


Figure 9. Sulfur Dioxide at 20th and Race Streets--1967

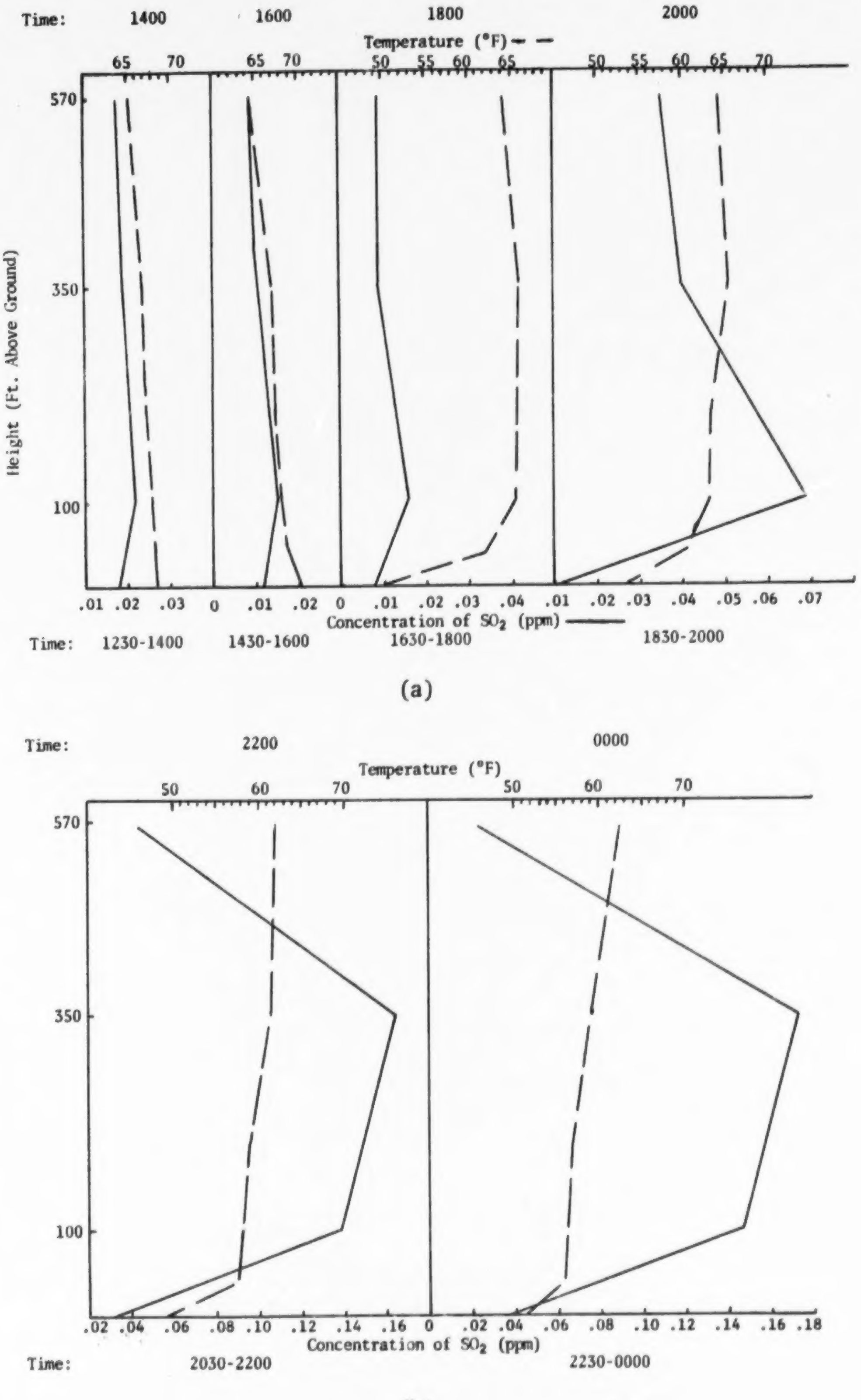


Figure 10. Vertical Distribution of Temperature and Sulfur Dioxide at the Philadelphia Tower--January 24, 1967

The concentrations at the 350 ft. level underwent wide fluctuations, the reasons for which are not clear. By late evening (10 P.M. to midnight), however, highest concentration of sulfur dioxide existed at 350 ft. Concentrations at that height then dropped to relatively low values for the next 6 hours, then rose to the absolute maximum value of 0.31 ppm between 6:30 and 8 A.M.

Principal sulfur dioxide sources are southwest of the city, and the tower is located at the northwest edge. Since winds were from the southwest during the January episode, measured concentrations at the tower location would be expected to be lower than those measured at the CAMP station in center city. The actual differences in measured ground level concentrations are shown in Table 3. The measurements at 100 ft. on the tower are also included, and a ratio of the ground level concentrations at the CAMP station to those at the tower. From these data, assuming the same ratio for concentrations at 100 ft., the concentrations at 100 ft. above center city are computed and shown in the last column of Table 3. These values are closer in order of magnitude to those being measured aloft over New York City by Davidson[3], where measured values go higher than 1.0 ppm on occasion.

Table 3

Comparison of sulfur dioxide measurements (ppm) at the tower and at the CAMP station, Philadelphia, Pennsylvania, January 24-25, 1967

Tower			CAMP Station			
Time	Concentrations (ppm)		Time	Concentrations (ppm)		
	Ground	100'		Ground (meas)	Ratio	100' (est)
1230-1400	0.018	0.022	1300-1400	0.10	5	0.11
1430-1600	0.012	0.015	1500-1600	0.16	13	0.20
1630-1800	0.008	0.016	1700-1800	0.18	22	0.36
1830-2000	0.010	0.069	1900-2000	0.22	22	1.5
2030-2200	0.031	0.14	2100-2200	0.10	3	0.42
2230-2400	0.038	0.15	2300-2400	0.20	5	0.75
0030-0200	0.11	0.17	0100-0200	0.22	2	0.34
0230-0400	0.067	0.15	0300-0400	0.30	4	0.60
0430-0600	0.050	0.18	0500-0600	0.22	4	0.72

VIII. A Model for the Buildup of SO_2 Concentrations in Philadelphia

Limited measurements to date would indicate that under inversion conditions sulfur dioxide emissions would be mostly restricted to the lower 500 ft. over Philadelphia, and a "typical" wind speed at the 100 ft. level under such conditions might be 3 mph.

The physical layout of the city is such that an area 10 miles wide and 15 miles long along a southwest to northeast axis would be representative of the surface area to be ventilated. Using a 500 ft. depth the volume to be ventilated is 14.2 cubic miles. The average rate of generation of sulfur dioxide in Philadelphia is estimated at 830 tons per day, mostly in the southwest.

Assuming fresh air flowing through the space at a fixed rate (ventilation rate), sulfur dioxide generated in that space at a fixed rate and instantaneously distributed throughout, then the rate at which the total volume of sulfur dioxide builds up in the space can be expressed as

$$dW = Pdt - v_r \frac{W}{V_a} dt$$

where W = weight of sulfur dioxide in the air at any time
P = rate of production of sulfur dioxide
= 830 tons per day = 2.64×10^{-6} cubic miles per hour
v_r = ventilation rate in cubic miles per hour
V_a = total volume of air = 14.2 cubic miles

Note that W/V_a = concentration, C.

For a wind speed of 3 mph, the ventilation rate is 2.84 cubic miles per hour. Solving the preceding equation for W and maximizing by letting $t \to \infty$, C = 1.0 ppm.

The concentration buildup is, of course, quite rapid in the early stages, then tends to level off. For example, it takes about 4 hours to reach a concentration of 0.5 ppm, half the maximum. A graph showing the rate at which concentrations build up for low ventilation rate is shown in Figure 12. This seems to be in relatively good agreement with observed concentrations under conditions of inversion and low wind speeds.

IX. Conclusions

The basic large scale weather pattern associated with the two high air pollution periods discussed in this paper features a stagnating anticyclone along the east coast with the resulting extended period of very light winds and marked atmospheric stability over Philadelphia.

The atmospheric stability was reflected in strong temperature inversions in the lower 350 to 500 ft. persisting from late afternoon until after sunrise daily throughout the period. Consistently low wind speeds were an even more persistent characteristic during the "episode" periods with the wind at the 40 ft. level practically never exceeding 4 knots.

Peak values of sulfur dioxide concentrations at ground level seem to be associated with bringing the pollutant down to ground level during the period of inversion breakup by solar heating after sunrise. Highest concentrations,

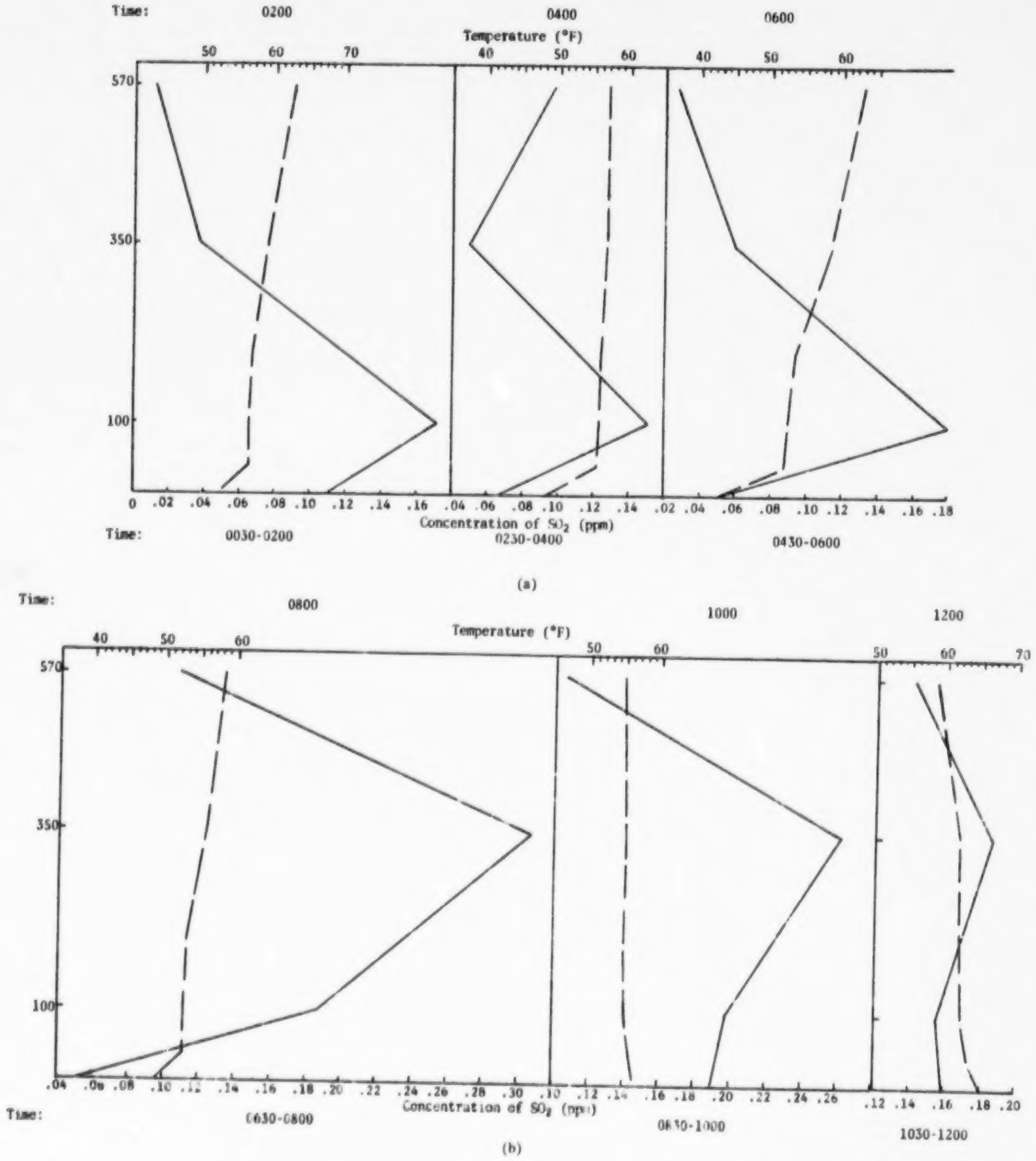


Figure 11. Vertical Distribution of Temperature and Sulfur Dioxide at the Philadelphia Tower--January 25, 1967

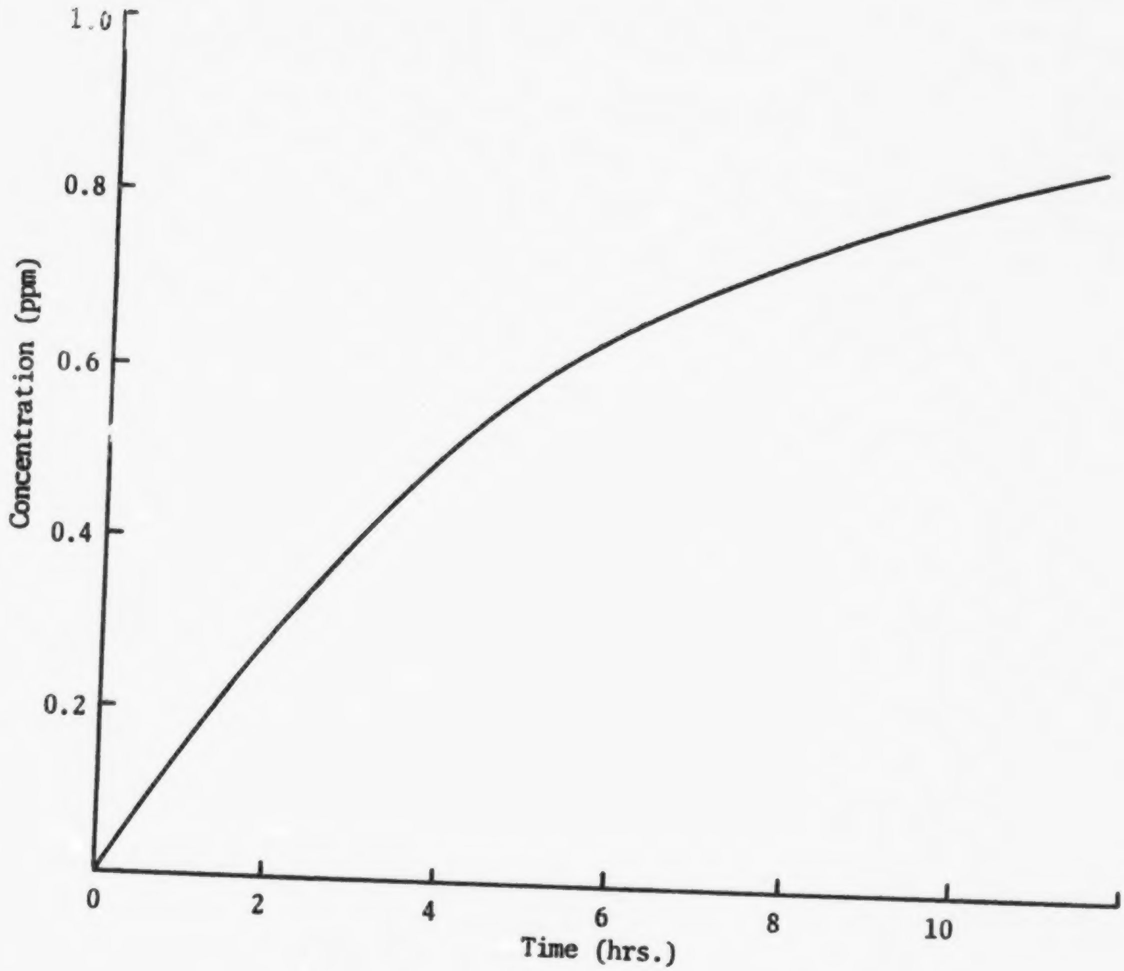


Figure 12. The Variation of Sulfur Dioxide Concentrations With Time With a Wind Speed of 3 mph Within a 500 ft. Depth Over Philadelphia

on the other hand, occur aloft but below 500 ft., perhaps near the 350 ft. level. By inference from tower data, sulfur dioxide concentrations aloft over downtown Philadelphia may reach levels well above 1 ppm during an episode such as the one which occurred in January, 1967.

The further indication here is that 200 ft. towers in a network such as that described by Munn and Stewart[9] would not be sufficiently high to record some air pollution and meteorological data of significance for analysis.

Acknowledgments

We would like to express our appreciation to WFIL-TV and KYW-TV for permission to use the tower, to WFIL-TV for services at and on the tower, to Walter Jackson for acquiring and graphing sulfur dioxide measurements on the tower, and to the Public Health Service and the City of Philadelphia for the use of the CAMP Station data on sulfur dioxide concentrations and Figures 5 and 9.

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APPENDIX B

A CASE STUDY OF A LIMITING METEOROLOGICAL SITUATION, NOVEMBER 11-23, 1953

Previous authors (Wexler, 1955; Fleagle et al., 1952) have described the importance of fog, low clouds, and associated meteorologic conditions to air pollution. The effect of fog and low clouds on the temperature profile often results in inversions developing or strengthening, thus leading to increases in the concentration of pollutants at low levels. Fog is also of special importance in the downward transport of emission from stacks. The Donora, Pennsylvania disaster of 1948 was an example in which fog combined with severe atmospheric pollution to create an intense health hazard (Schrenk, Wexler et al., 1949). The occurrence of low level temperature inversions with fog provides unique opportunities for serious pollution episodes to develop.

A very unusual and limiting meteorologic situation occurred over the Delaware Valley area during the period November 11-23, 1953 at which time several elements of importance in the concentration of atmospheric pollutants occurred simultaneously and persisted for a significant period. While such a combination might not be expected more often than once in 5 to 10 years on the average, the possible seriousness of the conditions that could develop warrants our study of the event.

November, 1953, was warmer and slightly drier than normal. The weather was unusually mild from the 15th to the 25th. Specific comments on the conditions during this part of the month included:

> "Fog prevailed during the mornings in many areas from the 13th to the 17th, and from the 18th to the 22nd a heavy pall of industrial smoke hung over the State /New Jersey/, which appeared to be combined with fog and was commonly referred to as smog. During the period, many people complained of irritation to eyes and throat. The smog was largely cleared up by wind and rain on the 23rd."
> (U. S. Weather Bureau, 1953a)
>
> ". . . fog which was heavy enough in the Atlantic States on the 14th to restrict travel both in the air and on the ground. . . . heavy pall of industrial smoke over State, until dispelled by moderate rainfall and wind."
> (U. S. Weather Bureau, 1953b)

A portion of the U. S. Weather Bureau Daily Weather Map series for the period November 11 to November 22, 1953 is included as figure 1 to show the day-to-day changes in the surface and 700-millibar (approximately 10,000 feet) pressure and wind patterns.

At the beginning of the episode a mass of continental polar air covered the Atlantic and Gulf states, and a second colder and drier continental polar air mass was approaching the Delaware Valley area behind a cold front which extended southwestward from a low center over Lake Erie. This frontal system passed the Delaware Valley area during the night of November 11-12 and was well out to sea by noon November 12. A large high pressure area covered the whole eastern half of the country by the noon map of November 12. This high continued over the eastern half of the country until November 15 when it slowly was pushed southward by a frontal system crossing the New England states. The high re-established itself on the 17th and then drifted very slowly eastward until it finally moved off the east coast by November 21.

The presence of the high pressure area during this period kept the Middle Atlantic area free of any frontal passages and so maintained the same stagnant air mass over the area. Winds were light near the center of the high pressure area and the generally descending air in the anticyclone greatly reduced the atmosphere's ability to transport or disperse its pollution load.

The upper level circulation, also included on figure 1, shows a weak trough of low pressure over the east coast area on November 11 which moved eastward on November 12 so that the area was covered by a ridge of high pressure extending northeastward from a center over the Gulf states. Winds maintained themselves from the northwest with relatively low wind speeds during the next few days and it was not until the 16th that speeds began to increase. Northwest winds slowly gave way to westerly and finally southwesterly winds aloft during the period November 17 to November 22 as the high pressure area aloft moved eastward from the Gulf states to the Bermuda area.

The great stability of the air during this period can be seen from the upper-air temperature soundings taken at Lakehurst, New Jersey during the period. The results are included in table 1 covering the period from November 13 to 23. The right-hand column of the table gives the temperature lapse rate in degrees Fahrenheit per 600 ft to make the data comparable to the earlier-mentioned data from the Springfield, Delaware County radiosonde station. The table shows that an inversion first appeared on the evening of November 13 and continued until the morning observation of November 15. An inversion again existed at the time of the evening observation on the 15th but was not present at 10 AM on the 16th. By evening of the 16th the inversion had returned and continued to exist on both the morning and evening radiosonde observations until the evening of the 19th. Again it was found on the next evening sounding and continued until the evening of the 22nd.

The stable inversion conditions existed almost continuously for 10 days although brief periods with small decreases in temperature with height did exist from time to time. These brief periods were clearly not long enough or unstable enough for the accumulated pollutants in the lower atmosphere to be dispersed or mixed with overlying air layers to any great degree.

The weather observations showed that fog occurred each day for the entire period from November 12-23. Visibility was zero or near zero early in the morning on four of the six days between November 16 and 22. Smog was often reported instead of fog indicating that atmospheric pollutants were well mixed with the water droplets and that the fog and adverse pollution conditions were developing hand in hand.

Table 1

Atmospheric Temperatures from Radiosonde Soundings at Naval Air Station, Lakehurst, New Jersey: November 13-23, 1953

10:00 a.m. EST

Date	Temp. at Surface (°F)*	Temp. at 1000 mb (°F)	Temp. at 950 mb (°F)	Temp. at 900 mb (°F)	Elev. above sfc at 1000 mb (feet)*	Inversion** (°F/600')
13	45.0	44.2	39.9	35.2	882	-0.5
14	41.0	43.0	37.8	34.7	794	+1.5
15	43.9	41.8	52.2	49.6	479	-2.7
16	54.5	52.5	45.3	48.6	515	-2.3
17	54.0	56.1	58.1	56.1	541	+2.4
18	63.0	63.5	60.8	55.2	679	+0.5
19	47.0	55.0	58.5	53.1	699	+7.0
20	58.5	61.3	57.4	52.2	712	+2.4
21	53.2	60.1	55.2	50.7	705	+5.8
22	55.4	60.8	58.6	56.8	686	+4.7
23	57.4	56.8	51.4	48.9	299	-1.1
10:00 p.m. EST						
13	41.0	47.1	43.0	39.2	817	+4.5
14	37.0	37.8	46.0	44.4	630	+0.7
15	54.7	55.4	55.6	48.9	403	+1.1
16	48.9	55.4	61.5	57.4	538	+7.2
17	50.4	63.7	59.4	59.2	594	+13.5
18	52.5	60.4	58.6	56.1	653	+7.3
19	63.7	63.1	60.3	54.7	715	-0.5
20	59.7	62.2	60.6	55.9	659	+2.3
21	54.9	63.5	60.6	57.4	669	+7.7
22	63.0	62.6	62.6	57.2	328	-0.7
23	48.9	49.1	50.2	46.0	213	+0.5

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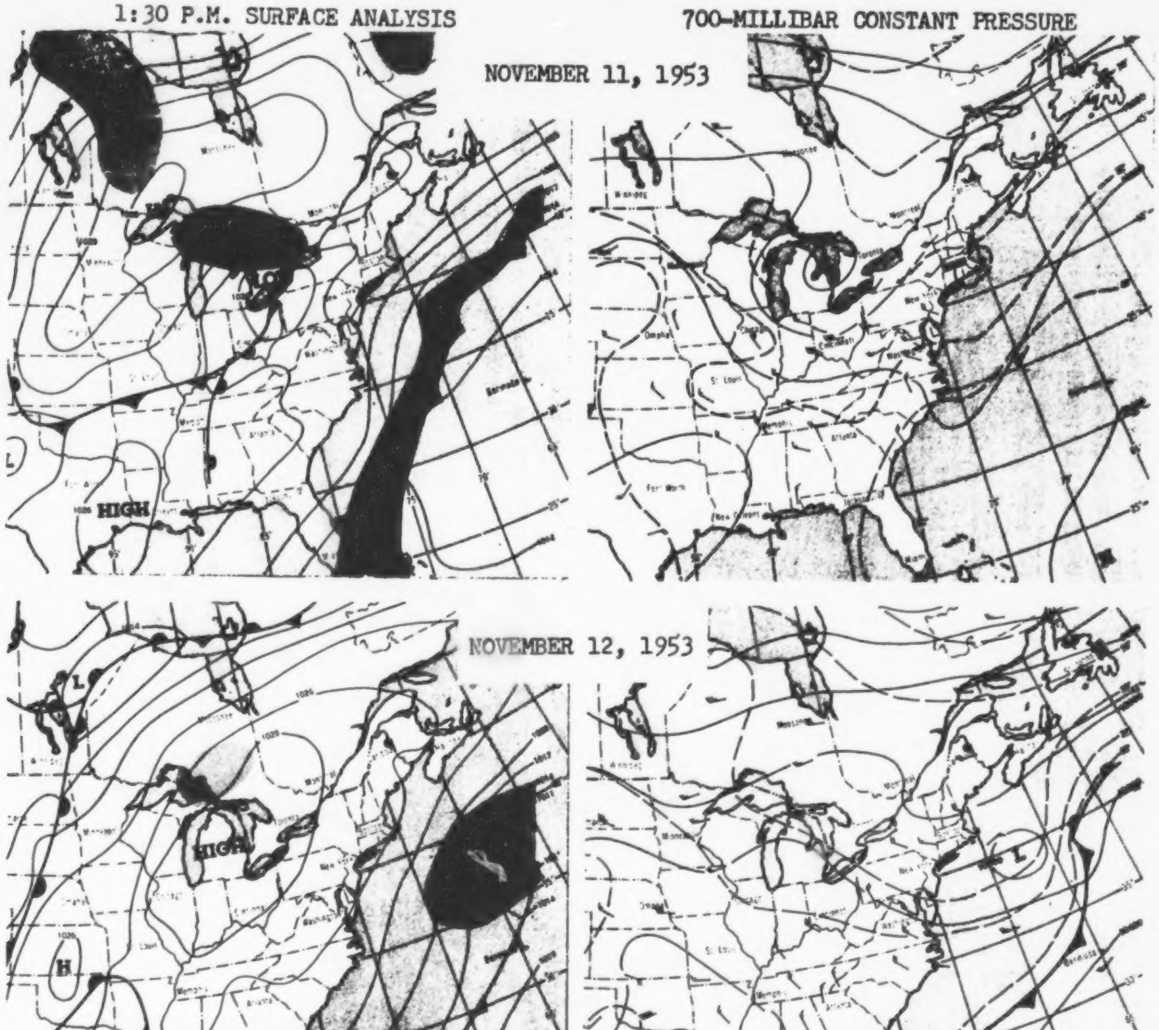
* Computed from basic data in °C and meters.

** Temperature difference between surface and 1000 mb constant pressure level.



1:30 P.M. SURFACE ANALYSIS

700-MILLIBAR CONSTANT PRESSURE

NOVEMBER 11, 1953

NOVEMBER 12, 1953

NOVEMBER 13, 1953

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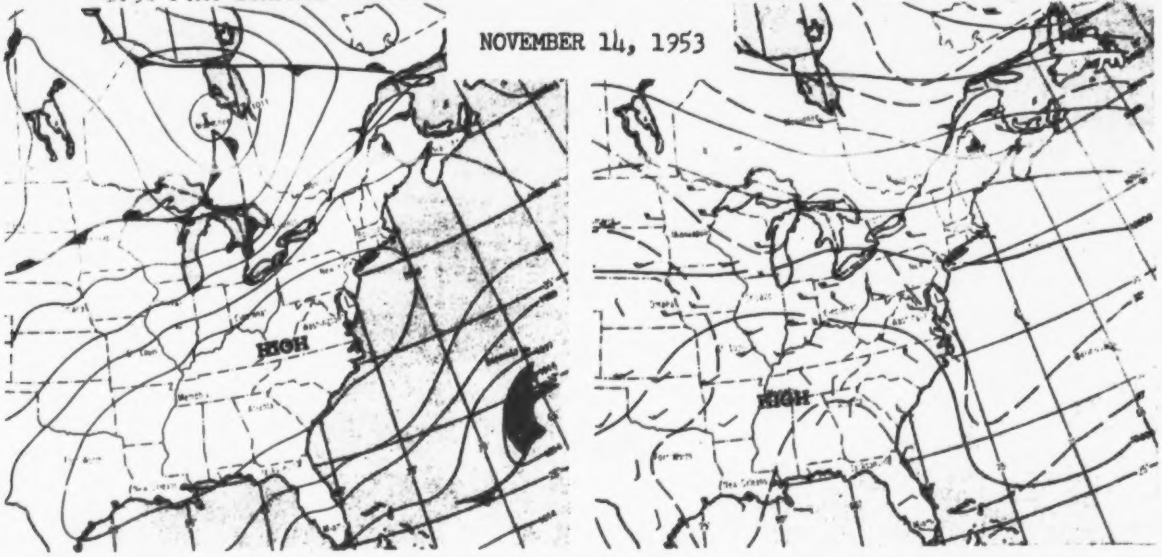
Figure 1

1:30 P.M. SURFACE ANALYSIS 700-MILLIBAR CONSTANT [illegible]

NOVEMBER 14, 1953



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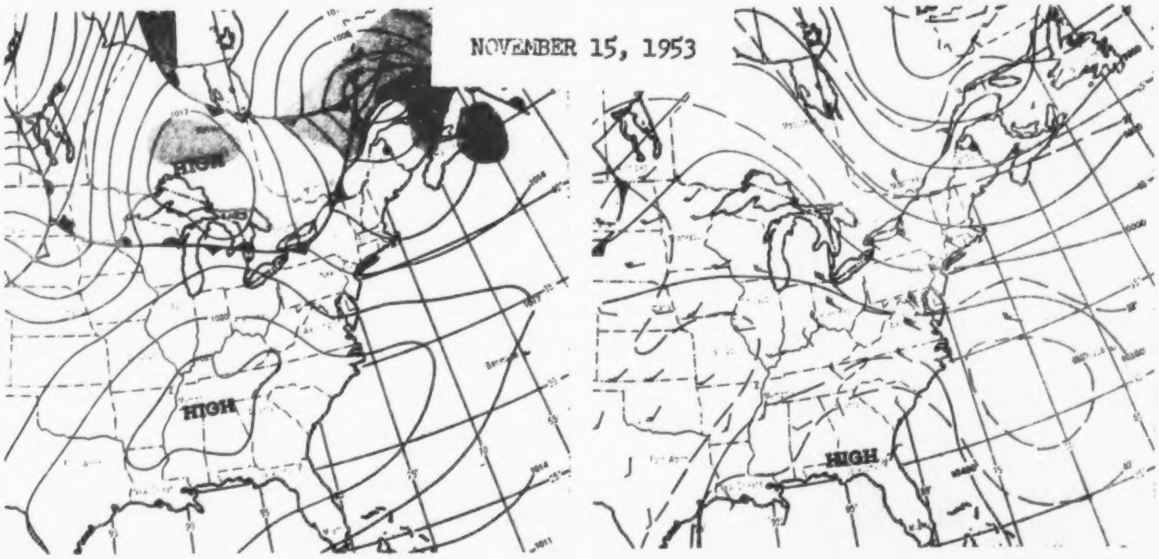
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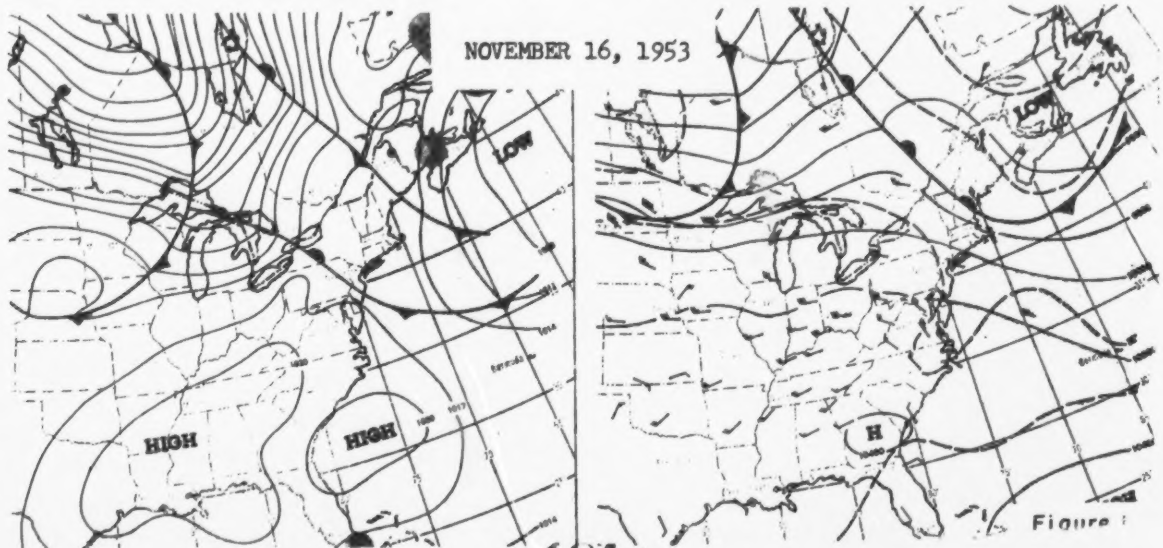
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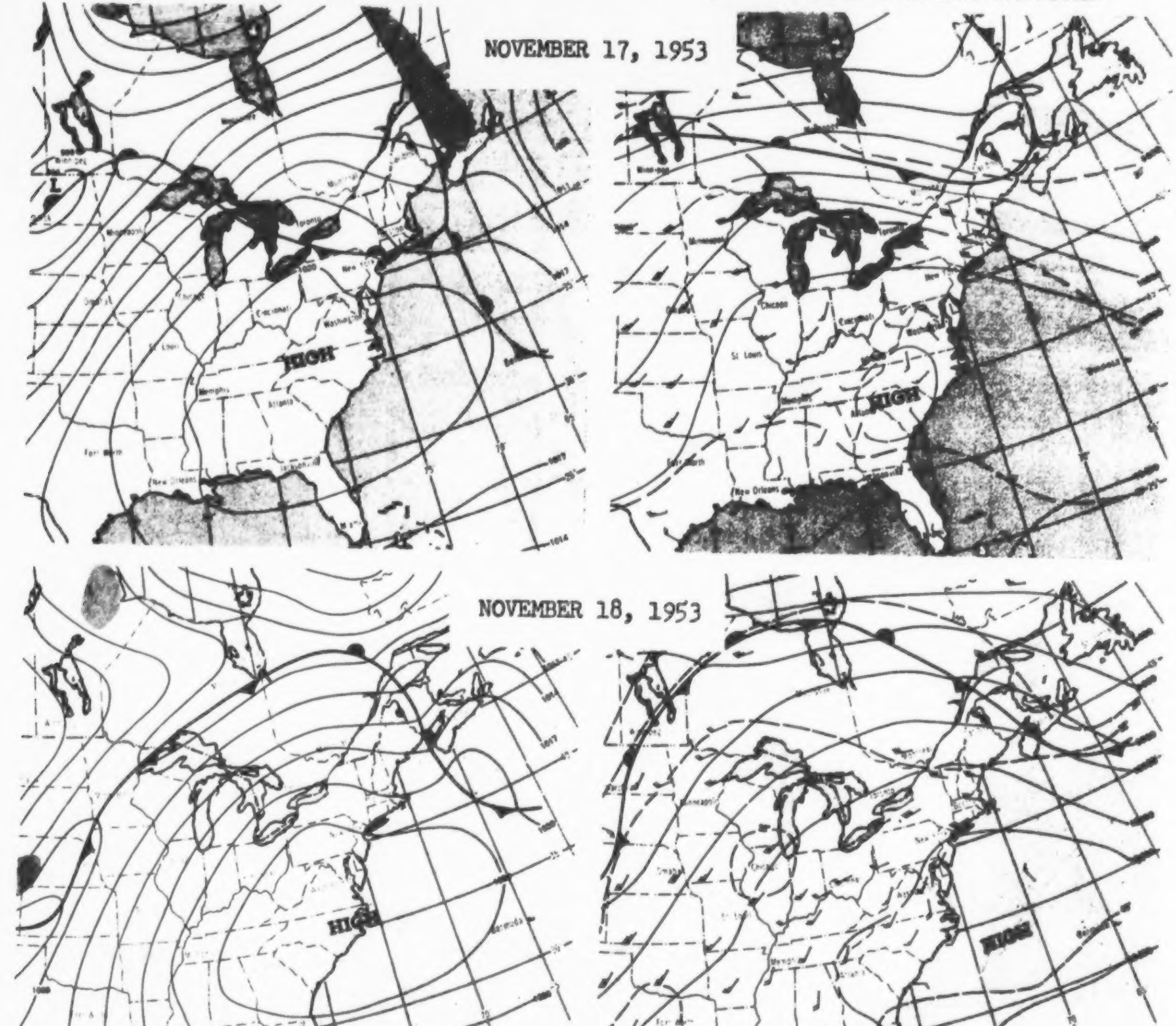
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1:30 P.M. SURFACE ANALYSIS

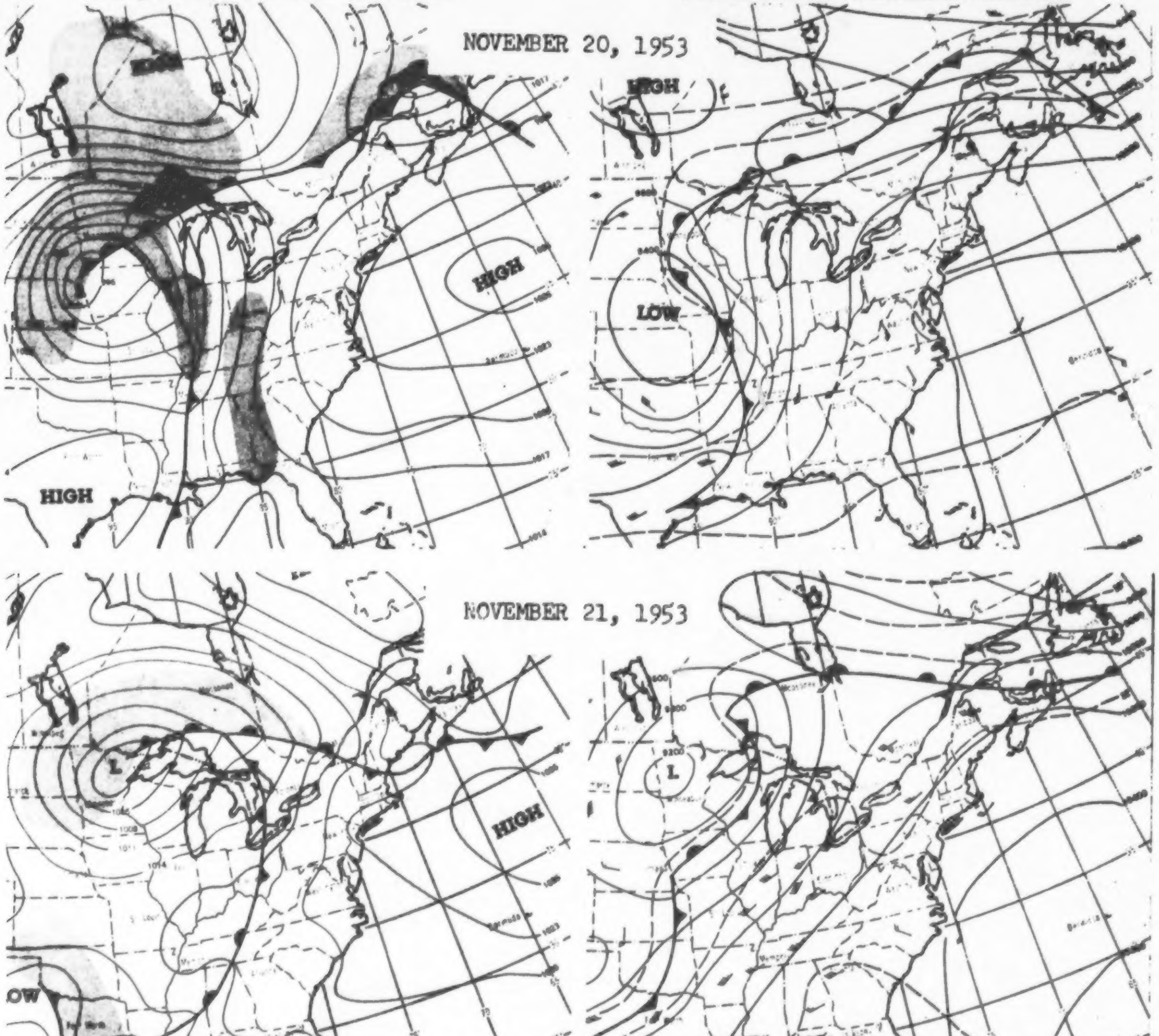
700-MILLIBAR CONSTANT PRESSURE

NOVEMBER 17, 1953

NOVEMBER 18, 1953

NOVEMBER 19, 1953

Figure 1



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HIGH

1:30 P.M. SURFACE ANALYSIS

700-MILLIBAR CONSTANT PRESSURE

NOVEMBER 20, 1953

NOVEMBER 21, 1953

NOVEMBER 22, 1953

Figure 1

This weather situation, while unique because of its length and severity could occur in any year during the fall. November 11-16, 1952 experienced a similar situation with a slow moving high pressure area resulting in a temperature inversion and fog. The likelihood of such a severe situation occurring more than once every few years is not great although the possibility of stagnant high pressure areas in the fall of the year with attendant high pollution conditions must always be considered.

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APPENDIX C

Daily Values of Soiling Index and Suspended Particulate Concentration at Three Philadelphia Stations, 1965

Station: 1501 E. Lycoming Street   Soiling Index (COH Units/1000 ft)x100

Date	Values for Days by Month											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	47	142	51	53	30	57e	33	40	53	66	56	158
2	121	79	85	53	61	138	87	73	63	56	61	197
3	38	74	116	33	65	38	56	72	104	59	121	283
4	64	106	149	36	37	56	48	122	48	38	104	130
5	213	126	51	100	*	93	41	66	29	65	87	84
6	112	181	76	81	17	66	63	91	46	114	180	104
7	311	94	40	60	*	126	71	69	86	83	158	87
8	188	106	67	116	41	98	69	31	109	79	123	179
9	118	58	81	43	51	91	130	63	63	87	37	153
10	45	68	74	36	105	72	49	75	116	68	49	196
11	134	101	42	54	80	88	45	67	65	73	116	215
12	215	230	46	64	58	50	68	125	27	81	86	76
13	352	43	50	20	46	46	92	108	54	104	91	131
14	81	37	93	30	37	71	103	72	75	164	63	184
15	76	164	58	96	44	43	85	92	86	77	96	105
16	46	180	75	50	77	46e	64	154	60	51	128	227
17	65	72	67	45	69	68	80	92	38	36	66	174
18	98e	79	58	36	38	86	64	87	72	211	47	130e
19	*	40	57	56	69	91	44	80	60	144	107	*
20	*	73	51	84	57	85	42	43	81	167	144	112e
21	218e	85	36	104	36	104	56	50	69	101	176	119
22	303	60	59	64	64	120	86	39	70	55	147	262
23	87	63	85	69	43	108	64	53	54	60	134	334
24	60	83	61	43	46	85	73	54	58	31	91	209
25	121	56	67	34	*	41	45	114	43	70	113	89
26	200	53	67	89	72	32	50	88	69	152	174	27
27	63	70	34	54	99	51	81	72	49	103	79	146
28	148	95	62	43	47	75	68	38	60	67	74	193
29	79	-	55	45	56	92	57	28	98	64	77	306
30	95	-	45	74	38	85	84	43	67	105	108	411
31	76	-	27	-	*	-	55	65	-	90	-	302
Mean	130	94	64	59	55	77	66	73	66	88	103	177

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* Value not reported and/or invalid
e estimated

Station: 3200 Frankford Avenue Soiling Index (COH Units/1000 ft)x100

Date	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
	Values for Days by Month											
1	81	164e	157	85	51	112	64	27	51	73	95e	142
2	173	141e	186	123	99	138	77	67	101	58	*	202
3	82	*	212	63	122	91	52	60	137	77	158e	335
4	108	130e	244	62	120	89	55	148	81	75	155	131
5	273	153	165	133	61	75	47	111	32	132	146	113
6	192	232	135	152	73	51	73	72	60	161	202	138
7	354	172	76	125	*	104	67	57	139	179	140	135
8	200	134	114	138	*	94	61	44	118	106	168	204
9	162	*	117	124e	*	85	120	73	119	111	101	219
10	*	249	86	*	77e	74	42	62	134	121	161	248
11	*	195	76	*	100	60	57	72	110	119	208	287
12	270e	304	86	107	76	66	86	120	51	114	185	116
13	118	86	89	57	116	60	113	116e	119	134	125	208
14	*	75	118	67	84	83	91	106	111	215	80	213e
15	185e	181	107	135	68	98	83	82	84	122	144	121e
16	131	228	129	82	98	85	85	100	92	93	158	233
17	106	158	147	53	92	91	68	85	117	79	86	158
18	190	136	168	61	72	76	55	93	79	184	77	103
19	123	134	106	166	141	68	68	95	84	204	146	82
20	146	91	100	132	107	53	66	86	115	238	182	126
21	159	153	73	183	102	96	88	74	87	228	203	174
22	297	133	*	107	77	96	78	46	99	133	238	233
23	204	112e	144e	187	60	105	52	82	67	92	147	312
24	132	206	150	94	*	69	73	80	95	66	154	179
25	152	91	185	111	*	*	42	172	73	111	145	70
26	261	91	159	104	76e	*	73	82	111	197	224	61
27	*	135	*	133	142	*	96	89	113	139	81	171
28	*	160	*	101	52e	75	94	57	128	127	98	171
29	138e	-	163e	105	51	67	81	34	153	156	92	245
30	151	-	83e	136	39	163	141	59	148	165	158	292
31	151	-	70	-	105	-	70	83	-	214	-	218
Mean	175	156	130	112	87	86	75	82	100	136	147	182

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* Value not reported and/or invalid

e estimated

Station: 500 S. Broad Street Soiling Index (COH Units/1000 ft)x100

Date	Values for Days by Month											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	*	148	98e	84	110	57	31	*	56	44	67	134
2	*	128	149	111	*	82	68	*	67e	45	84	178
3	*	116	222	69	66e	40	45	*	99	62	133	199
4	*	118	142	57e	105	46	49	*	61	53	113	112
5	*	145	75	*	47	57	52	*	56	82	85	98
6	*	176	94	115	72	50	52	*	51	107	146	109
7	*	168	74	63	58	45	61	54	116	100	120	115
8	171e	126	102e	106	59	59	39	36	97	63e	122	160
9	126	90	90	79	47	48	94	49	67	57e	65	152
10	94	119	83	54	84e	62	41	45	78	85	100	205
11	169	147	66	70	36	48	54	42	84	80	151	189
12	176	271	74	83	42	63	81	69	33	82	96	100
13	265	59	74	49e	63	37	74	92	83	84	103	166
14	106	63	114	85	40	43	79	90	99	99	87	160
15	134	157	100	89	48	51	61	*	53	66	125	109
16	144	177	104	50	55	44	66	83e	70	62	123	167
17	96	111	68	56	46	56	58	68	61	45	68	153
18	196	86	111	37	52	78	35	50	69	141	64	124
19	118	75	83	101e	79	58	49	64	74	123	106	101
20	154	*	87	91	64	57	40	47	43e	164	117	103
21	142	*	61	124	40	77	67	54	*	132	149	145
22	241	*	*	64	36	86	72	45	*	71	153	181
23	133	*	115e	81	50	83	47	70	*	72	127	208
24	102	*	126	89	49e	74	61	61	*	56	128	158
25	150	*	88	68	51	41	51	114	*	87	141	100
26	188	*	115	84	46e	52	49	68	*	146	155	48
27	81	*	60	84	75	52	81	70	*	108	76	129
28	108	*	70	63	43	52	81	53	*	98	100	147
29	110	-	89	83	39	61	63	22	68e	82	80	*
30	134	-	75	39	23	94	101e	39	72	136	114	251e
31	128	-	90	-	52	-	*	78	-	108	-	186
Mean	144	131	97	77	56	58	60	61	71	88	110	146

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* Value not reported and/or invalid

e estimated

Station: 1501 E. Lycoming Street Suspended Particulates (μg/m³)

Date	Values for Days by Month											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	61	234	105	107	128	152	79	89	149	114	96	156
2	59	188	206	79	176	204	135	119	96	72	83	125
3	65	192	279	52	272	146	103	87	136	77	226	297
4	125	162	216	58	253	103	65	140	73	59	158	108
5	207	225	108	138	115	149	146	158	52	65	142	48
6	232	238	103	131	190	146	107	173	94	154	256	84
7	266	99	61	92	127	184	160	134	186	137	177	81
8	274	90	77	228	80	130	110	93	139	132	142	179
9	68	89	108	75	121	126	176	115	141	105	62	171
10	46	95	97	71	187	132	84	99	217	72	74	193
11	243	150	81	86	188	124	58	87	134	116	111	201
12	621	247	74	195	99	118	120	166	64	126	96	52
13	291	69	109	106	134	96	133	151	65	127	139	84
14	93	85	107	75	119	90	129	148	130	249	55	185
15	122	348	120	184	151	85	79	153	207	151	190	98
16	48	283	146	77	183	66	130	249	97	63	154	233
17	146	178	84	87	134	84	93	197	118	95	76	222
18	152	186	116	46	113	114	159	191	148	279	83	90
19	194	113	92	91	174	87	74	149	98	161	99	61
20	135	92	76	190	106	123	69	89	230	267	139	70
21	259	104	79	198	140	191	102	102	189	173	190	106
22	337	108	151	120	177	160	117	57	189	105	106	245
23	51	155	124	152	103	168	186	86	131	79	111	350
24	85	96	119	75	122	145	173	91	144	50	83	196
25	178	107	85	82	167	81	89	165	58	86	102	55
26	187	127	141	183	124	97	106	167	117	177	153	51
27	145	215	74	103	226	99	149	131	86	121	69	150
28	167	92	134	96	116	188	144	105	97	98	68	130
29	123	-	89	104	76	126	109	48	150	70	73	270
30	133	-	67	151	60	92	154	70	141	177	230	306
31	136	-	61	-	104	-	121	118	-	206	-	291
Mean	169	156	112	114	144	127	118	127	129	128	125	158

Station: 3200 Frankford Avenue

Suspended Particulates ($\mu g/m^3$)

Date	Values for Days by Month											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	91	262	160	126	174	173	97	85	218	103	135	190
2	89	182	263	140	181	249	162	125	133	98	101	154
3	95	217	364	79	278	139	163	123	187	90	247	421
4	200	220	317	76	231	120	95	191	107	84	224	132
5	255	280	271	155	152	160	112	142	68	98	158	90
6	290	262	163	137	236	173	105	183	94	176	284	128
7	279	112	107	192	165	227	155	175	149	220	209	122
8	265	125	136	236	112	200	124	107	190	155	187	267
9	78	155	134	122	159	152	174	117	197	121	91	212
10	81	189	141	89	233	164	92	118	274	84	139	237
11	229	191	149	114	234	139	67	122	136	144	167	326
12	582	290	124	208	133	106	129	172	98	145	151	81
13	233	85	131	123	200	146	167	198	96	172	142	172
14	122	112	152	86	147	114	193	129	151	278	84	207
15	178	345	144	222	170	153	111	164	168	222	146	143
16	89	298	163	99	200	127	129	250	120	109	191	254
17	170	219	145	102	157	133	176	252	201	67	107	205
18	151	164	192	64	124	150	140	253	162	254	88	100
19	186	168	109	133	230	125	107	197	132	200	134	102
20	155	126	137	202	142	128	93	111	281	312	179	99
21	270	140	103	233	219	165	103	142	202	261	236	138
22	535	148	181	142	190	272	180	76	186	149	142	261
23	92	216	160	214	123	214	174	120	156	99	134	219
24	90	190	161	91	139	193	195	105	159	76	117	297
25	178	157	138	84	192	90	109	204	92	136	134	98
26	205	165	178	168	127	93	113	140	141	227	220	80
27	199	242	100	135	260	138	193	153	116	173	95	256
28	210	149	137	112	148	210	171	125	147	149	85	171
29	161	–	140	133	109	149	136	63	195	101	140	345
30	176	–	95	186	68	132	199	98	217	207	281	380
31	194	–	89	–	126	–	121	169	–	268	–	378
Mean	196	193	160	140	173	156	138	148	159	160	158	202

Station: 500 S. Broad Street

Suspended Particulates (µg/m³)

Date	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
	Values for Days by Month											
1	92	219	154	115	128	121	75	78	129	167	102	128
2	129	187	124	124	188	182	147	80	101	66	96	210
3	88	133	289	93	218	77	114	96	165	106	183	264
4	165e	161	222	105	218	85	85	91	137	92	224	107
5	209e	161	99	155	148	122	105	243	77	96	147	85
6	238e	218	135	190	199	118	123	65	107	135	245	120
7	237	128	90	116	103	131	133	107	197	152	208	125
8	213e	143	138	235	99	135	103	66	185	100	181	184
9	141	107	138	133	151	127e	161	63	168	101e	84	197
10	69e	106	113	104	232	132	86	91	185	118	87	253
11	189e	168	117	113	176	122	79	87	141	115	349	284
12	211	228	154	229	114	131	154	146	119	111	73	127
13	192e	93	104	117	193	134	135	157	141	98	56	86
14	110	78	129	170	113	101	176	148	145	173	81	267
15	240	205	101	183e	148	115	114	173	127	107	130	91
16	117	280	168	83e	171	159	127	185	149	107	131	191
17	95	183	113	86e	123	122	151	145	91	87	94	145
18	152	163	149	71	59	140	101	118	290	210	88	92
19	112	139e	147	128	271	107	91	114	77	175	110	75
20	138	105e	120	225	148	110	87	97	178	98	179	56
21	222e	117e	114	218	169	184	112	122	116	480	198	168
22	414	123e	155	147	159	201	141	77	60	132	182	211
23	228	140	162	176e	125	204	89	111	132	91	109	290
24	110	159	185	130	116	144	154	88e	95	70	102	152
25	117	104	133	71e	147	88	107	123	76	122	113	54
26	190	113	194	139e	106e	111	108	120	82	186	121	64
27	117	150	101	147	272	85	197	80	127	145	76	144
28	166	137	114e	130	126	144	260	54	168	150	92	130
29	156	-	160	145	84	151	113e	74	158	103	83	216
30	162	-	80e	147	87	171	165e	181	102	183	127	334
31	189	-	102	-	115	-	101e	85	-	219	-	254
Mean	167	152	139	141	152	132	125	112	134	139	135	165

ᵉ estimated

APPENDIX D*

WFIL-KYW TV Tower, Philadelphia, Pa.
Wind Distribution - Speed vs Direction
January 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	40	30	12	0	0	0	0	0	0	0	0	0	82
PER	5	98	73	29	0	0	0	0	0	0	0	0	0	202
FCY	6TO	22	23	11	0	0	0	0	0	0	0	0	0	56
PER	15	54	56	27	0	0	0	0	0	0	0	0	0	137
FCY	16TO	20	32	11	0	0	0	0	0	0	0	0	0	63
PER	25	49	78	27	0	0	0	0	0	0	0	0	0	154
FCY	26TO	24	26	9	0	0	0	0	0	0	0	0	0	59
PER	35	59	64	22	0	0	0	0	0	0	0	0	0	145
FCY	36TO	26	22	7	0	0	0	0	0	0	0	0	0	55
PER	45	64	54	17	0	0	0	0	0	0	0	0	0	135
FCY	46TO	13	17	11	2	0	0	0	0	0	0	0	0	43
PER	55	32	41	27	4	0	0	0	0	0	0	0	0	104
FCY	56TO	22	15	16	4	1	0	0	0	0	0	0	0	58
PER	65	54	36	39	9	2	0	0	0	0	0	0	0	140
FCY	66TO	14	21	27	5	0	0	0	0	0	0	0	0	67
PER	75	34	51	66	12	0	0	0	0	0	0	0	0	163
FCY	76TO	16	32	16	8	6	0	0	0	0	0	0	0	78
PER	85	39	78	39	19	14	0	0	0	0	0	0	0	189
FCY	86TO	8	10	13	8	0	0	0	0	0	0	0	0	39
PER	95	19	24	32	19	0	0	0	0	0	0	0	0	94
FCY	96TO	6	9	8	0	0	0	0	0	0	0	0	0	23
PER	105	14	22	19	0	0	0	0	0	0	0	0	0	55
FCY	106TO	9	5	1	0	0	0	0	0	0	0	0	0	15
PER	115	22	12	2	0	0	0	0	0	0	0	0	0	36
FCY	116TO	13	0	0	0	0	0	0	0	0	0	0	0	13
PER	125	32	0	0	0	0	0	0	0	0	0	0	0	32
FCY	126TO	25	0	0	0	0	0	0	0	0	0	0	0	25
PER	135	61	0	0	0	0	0	0	0	0	0	0	0	61
FCY	136TO	23	5	0	0	0	0	0	0	0	0	0	0	28
PER	145	56	12	0	0	0	0	0	0	0	0	0	0	68
FCY	146TO	22	29	1	0	0	0	0	0	0	0	0	0	52
PER	155	54	71	2	0	0	0	0	0	0	0	0	0	127
FCY	156TO	24	32	1	0	0	0	0	0	0	0	0	0	57
PER	165	59	78	2	0	0	0	0	0	0	0	0	0	139
FCY	166TO	21	10	0	0	0	0	0	0	0	0	0	0	31
PER	175	51	24	0	0	0	0	0	0	0	0	0	0	75
FCY	176TO	44	23	4	0	0	0	0	0	0	0	0	0	71
PER	185	108	56	9	0	0	0	0	0	0	0	0	0	173
FCY	186TO	47	106	16	0	0	0	0	1	0	0	0	0	170
PER	195	115	261	39	0	0	0	0	2	0	0	0	0	417
FCY	196TO	29	81	15	1	0	0	0	0	0	0	0	0	126
PER	205	71	199	36	2	0	0	0	0	0	0	0	0	308
FCY	206TO	39	48	15	0	0	0	0	0	0	0	0	0	102
PER	215	96	118	36	0	0	0	0	0	0	0	0	0	250
FCY	216TO	45	30	7	0	0	0	0	0	0	0	0	0	82
PER	225	110	73	17	0	0	0	0	0	0	0	0	0	200
FCY	226TO	54	39	6	0	0	0	0	0	0	0	0	0	99
PER	235	133	96	14	0	0	0	0	0	0	0	0	0	243
FCY	236TO	45	35	6	0	0	0	0	0	0	0	0	0	86
PER	245	110	86	14	0	0	0	0	0	0	0	0	0	210
FCY	246TO	53	23	2	0	0	0	0	0	0	0	0	0	78
PER	255	130	56	4	0	0	0	0	0	0	0	0	0	190
FCY	256TO	56	21	4	6	0	0	0	0	0	0	0	0	87
PER	265	137	51	9	14	0	0	0	0	0	0	0	0	211
FCY	266TO	43	27	31	30	6	0	0	0	0	0	0	0	137
PER	275	105	66	76	73	14	0	0	0	0	0	0	0	334
FCY	276TO	49	51	25	11	1	0	0	0	0	0	0	0	137
PER	285	120	125	61	27	2	0	0	0	0	0	0	0	335
FCY	286TO	93	92	35	1	0	0	0	0	0	0	0	0	221
PER	295	229	226	86	2	0	0	0	0	0	0	0	0	543
FCY	296TO	84	168	62	10	0	0	0	0	0	0	0	0	324
PER	305	206	413	152	24	0	0	0	0	0	0	0	0	795
FCY	306TO	89	120	127	39	0	0	0	0	0	0	0	0	375
PER	315	219	295	312	96	0	0	0	0	0	0	0	0	922
FCY	316TO	67	106	107	51	19	0	0	0	0	0	0	0	350
PER	325	165	261	263	125	46	0	0	0	0	0	0	0	860
FCY	326TO	68	130	56	18	4	0	0	0	0	0	0	0	276
PER	335	167	320	137	44	9	0	0	0	0	0	0	0	677
FCY	336TO	64	82	27	3	0	0	0	0	0	0	0	0	176
PER	345	157	202	66	7	0	0	0	0	0	0	0	0	432
FCY	346TO	47	36	12	0	0	0	0	0	0	0	0	0	95
PER	355	115	88	29	0	0	0	0	0	0	0	0	0	232
	SUM	1364	1536	701	197	37	0	0	1	0	0	0	0	
		3354	3766	1710	477	87	0	0	2	0	0	0	0	

Total No. Observations = 4058
Frequency Calm = 222 Per cent Calm = 5.47
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

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*These data are part of a more complete data summary which appeared in "An Automated Meteorological Instrument and Observing System on a 1000 Ft. Television Tower," Final Report III, November 1967, U. S. Dept. of Commerce, ESSA, Weather Bureau, Systems Development Office, Contract Cwb-11133 by Dr. Herman Newstein, Drexel Institute of Technology, Philadelphia, Pa. Reproduced by permission of the author.

Wind Distribution - Speed vs Direction
February 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	42	37	4	0	0	0	0	0	0	0	0	0	83
PER	5	115	102	11	0	0	0	0	0	0	0	0	0	228
FCY	6TO	27	32	5	0	0	0	0	0	0	0	0	0	64
PER	15	74	88	13	0	0	0	0	0	0	0	0	0	175
FCY	16TO	31	18	8	0	0	0	0	0	0	0	0	0	57
PER	25	85	49	22	0	0	0	0	0	0	0	0	0	156
FCY	26TO	40	23	3	0	0	0	0	0	0	0	0	0	66
PER	35	110	63	8	0	0	0	0	0	0	0	0	0	181
FCY	36TO	28	24	2	0	0	0	0	0	0	0	0	0	54
PER	45	77	66	5	0	0	0	0	0	0	0	0	0	148
FCY	46TO	35	18	5	0	0	0	0	0	0	0	0	0	58
PER	55	96	49	13	0	0	0	0	0	0	0	0	0	158
FCY	56TO	38	13	2	0	0	0	0	0	0	0	0	0	53
PER	65	104	35	5	0	0	0	0	0	0	0	0	0	144
FCY	66TO	23	17	7	1	0	0	0	0	0	0	0	0	48
PER	75	63	46	19	2	0	0	0	0	0	0	0	0	130
FCY	76TO	30	16	3	2	0	0	0	0	0	0	0	0	51
PER	85	82	44	8	5	0	0	0	0	0	0	0	0	139
FCY	86TO	36	16	9	1	0	0	0	0	0	0	0	0	62
PER	95	99	44	24	2	0	0	0	0	0	0	0	0	169
FCY	96TO	55	28	7	0	0	0	0	0	0	0	0	0	90
PER	105	151	77	19	0	0	0	0	0	0	0	0	0	247
FCY	106TO	36	18	2	0	0	0	0	0	0	0	0	0	56
PER	115	99	49	5	0	0	0	0	0	0	0	0	0	153
FCY	116TO	27	9	0	0	0	0	0	0	0	0	0	0	36
PER	125	74	24	0	0	0	0	0	0	0	0	0	0	98
FCY	126TO	18	11	2	0	0	0	0	0	0	0	0	0	31
PER	135	49	30	5	0	0	0	0	0	0	0	0	0	84
FCY	136TO	21	12	4	1	0	0	0	0	0	0	0	0	38
PER	145	57	33	11	2	0	0	0	0	0	0	0	0	103
FCY	146TO	16	10	6	4	1	0	0	0	0	0	0	0	37
PER	155	44	27	16	11	2	0	0	0	0	0	0	0	100
FCY	156TO	22	33	4	1	0	0	0	0	0	0	0	0	60
PER	165	60	91	11	2	0	0	0	0	0	0	0	0	164
FCY	166TO	20	22	3	0	0	0	0	0	0	0	0	0	45
PER	175	55	60	8	0	0	0	0	0	0	0	0	0	123
FCY	176TO	25	31	12	2	0	1	0	0	0	0	0	0	[illegible]
PER	185	69	85	33	5	0	2	0	0	0	0	0	0	[illegible]
FCY	186TO	40	85	45	2	0	0	0	0	0	0	0	0	172
PER	195	110	234	124	5	0	0	0	0	0	0	0	0	473
FCY	196TO	37	68	18	7	0	0	1	0	0	0	0	0	131
PER	205	102	187	49	19	0	0	2	0	0	0	0	0	359
FCY	206TO	45	36	26	6	1	0	2	1	0	0	0	0	117
PER	215	124	99	71	16	2	0	5	2	0	0	0	0	319
FCY	216TO	29	19	14	0	0	0	0	0	0	0	0	0	61
PER	225	80	49	38	0	0	0	0	0	0	0	0	0	167
FCY	226TO	30	23	18	2	0	0	0	0	0	0	0	0	73
PER	235	82	63	49	5	0	0	0	0	0	0	0	0	199
FCY	236TO	25	9	9	1	0	0	0	0	0	0	0	0	44
PER	245	69	24	24	2	0	0	0	0	0	0	0	0	119
FCY	246TO	35	8	11	2	0	0	0	0	0	0	0	0	56
PER	255	96	22	30	5	0	0	0	0	0	0	0	0	153
FCY	256TO	26	25	14	6	0	0	0	0	0	0	0	0	71
PER	265	71	69	38	16	0	0	0	0	0	0	0	0	194
FCY	266TO	50	38	29	7	0	0	0	0	0	0	0	0	124
PER	275	138	104	80	19	0	0	0	0	0	0	0	0	341
FCY	276TO	45	71	63	12	3	0	0	0	0	0	0	0	194
PER	285	124	196	173	33	8	0	0	0	0	0	0	0	534
FCY	286TO	63	90	69	14	0	0	0	0	0	0	0	0	236
PER	295	173	248	190	38	0	0	0	0	0	0	0	0	649
FCY	296TO	51	110	64	14	2	0	0	0	0	0	0	0	241
PER	305	140	303	176	38	5	0	0	0	0	0	0	0	662
FCY	306TO	63	73	54	22	3	0	0	0	0	0	0	0	215
PER	315	173	201	149	60	8	0	0	0	0	0	0	0	591
FCY	316TO	52	97	55	23	5	1	0	0	0	0	0	0	233
PER	325	143	267	151	63	13	2	0	0	0	0	0	0	639
FCY	326TO	74	89	52	10	1	0	0	0	0	0	0	0	226
PER	335	204	245	143	27	2	0	0	0	0	0	0	0	621
FCY	336TO	47	45	24	1	0	0	0	0	0	0	0	0	117
PER	345	129	124	66	2	0	0	0	0	0	0	0	0	321
FCY	346TO	44	42	7	2	0	0	0	0	0	0	0	0	95
PER	355	121	115	19	5	0	0	0	0	0	0	0	0	260
	SUM	1326	1315	660	143	16	2	3	1	0	0	0	0	
		3642	3612	1806	392	40	5	7	2	0	0	0	0	

Total No. Observations = 3621
Frequency Calm = 155 Per cent Calm = 4.28
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
March 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1- 5	6- 10	11- 15	16- 20	21- 25	26- 30	31- 35	36- 40	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TO	55	46	12	0	0	0	0	0	0	0	0	0	113
PER	5	131	109	28	0	0	0	0	0	0	0	0	0	268
FCY	6TO	47	40	5	0	0	0	0	0	0	0	0	0	92
PER	15	112	95	11	0	0	0	0	0	0	0	0	0	218
FCY	16TO	59	35	5	0	0	0	0	0	0	0	0	0	99
PER	25	141	83	11	0	0	0	0	0	0	0	0	0	235
FCY	26TO	49	31	3	0	0	0	0	0	0	0	0	0	83
PER	35	117	74	7	0	0	0	0	0	0	0	0	0	198
FCY	36TO	31	15	2	0	0	0	0	0	0	0	0	0	48
PER	45	74	35	4	0	0	0	0	0	0	0	0	0	113
FCY	46TO	21	25	1	0	0	0	0	0	0	0	0	0	47
PER	55	50	59	2	0	0	0	0	0	0	0	0	0	111
FCY	56TO	30	39	10	0	0	0	0	0	0	0	0	0	79
PER	65	71	93	23	0	0	0	0	0	0	0	0	0	187
FCY	66TO	35	40	12	4	1	0	0	0	0	0	0	0	92
PER	75	83	95	28	9	2	0	0	0	0	0	0	0	217
FCY	76TO	42	50	12	6	1	0	0	0	0	0	0	0	111
PER	85	100	119	28	14	2	0	0	0	0	0	0	0	263
FCY	86TO	50	45	10	2	2	0	0	0	0	0	0	0	109
PER	95	119	107	23	4	4	0	0	0	0	0	0	0	257
FCY	96TO	74	55	7	0	0	0	0	0	0	0	0	0	136
PER	105	176	131	16	0	0	0	0	0	0	0	0	0	323
FCY	106TO	54	27	0	0	0	0	0	0	0	0	0	0	81
PER	115	129	64	0	0	0	0	0	0	0	0	0	0	193
FCY	116TO	47	17	0	0	0	0	0	0	0	0	0	0	64
PER	125	112	40	0	0	0	0	0	0	0	0	0	0	152
FCY	126TO	27	18	1	0	0	0	0	0	0	0	0	0	46
PER	135	64	43	2	0	0	0	0	0	0	0	0	0	109
FCY	136TO	34	14	1	0	0	0	0	0	0	0	0	0	49
PER	145	81	33	2	0	0	0	0	0	0	0	0	0	116
FCY	146TO	30	13	2	0	0	0	0	0	0	0	0	0	45
PER	155	71	31	4	0	0	0	0	0	0	0	0	0	106
FCY	156TO	24	14	0	0	0	0	0	0	0	0	0	0	38
PER	165	57	33	0	0	0	0	0	0	0	0	0	0	90
FCY	166TO	25	10	8	1	0	0	0	0	0	0	0	0	44
PER	175	59	23	19	2	0	0	0	0	0	0	0	0	103
FCY	176TO	38	35	19	1	0	0	0	0	0	0	0	0	93
PER	185	90	83	45	2	0	0	0	0	0	0	0	0	220
FCY	186TO	41	76	27	5	1	0	0	0	0	0	0	0	150
PER	195	97	181	64	11	2	0	0	0	0	0	0	0	355
FCY	196TO	53	66	32	3	0	0	0	0	0	0	0	0	154
PER	205	126	157	76	7	0	0	0	0	0	0	0	0	366
FCY	206TO	65	66	33	3	0	0	0	0	0	0	0	0	167
PER	215	155	157	78	7	0	0	0	0	0	0	0	0	397
FCY	216TO	33	21	10	0	0	0	0	0	0	0	0	0	64
PER	225	78	50	23	0	0	0	0	0	0	0	0	0	151
FCY	226TO	32	25	12	0	0	0	0	0	0	0	0	0	69
PER	235	76	59	28	0	0	0	0	0	0	0	0	0	163
FCY	236TO	37	35	5	0	0	0	0	0	0	0	0	0	77
PER	245	88	83	11	0	0	0	0	0	0	0	0	0	182
FCY	246TO	44	29	3	4	0	0	0	0	0	0	0	0	80
PER	255	105	69	7	9	0	0	0	0	0	0	0	0	190
FCY	256TO	35	33	9	3	1	0	0	0	0	0	0	0	81
PER	265	83	78	21	7	2	0	0	0	0	0	0	0	191
FCY	266TO	44	27	13	7	1	0	0	0	0	0	0	0	92
PER	275	105	64	31	16	2	0	0	0	0	0	0	0	218
FCY	276TO	43	38	17	6	0	0	0	0	0	0	0	0	104
PER	285	102	90	40	14	0	0	0	0	0	0	0	0	246
FCY	286TO	58	61	33	4	0	0	0	0	0	0	0	0	156
PER	295	138	145	78	9	0	0	0	0	0	0	0	0	370
FCY	296TO	68	93	41	10	1	0	0	0	0	0	0	1	214
PER	305	162	222	97	23	2	0	0	0	0	0	0	2	508
FCY	306TO	79	96	66	16	1	0	0	0	0	0	0	0	258
PER	315	188	229	157	38	2	0	0	0	0	0	0	0	614
FCY	316TO	72	107	60	17	0	0	0	0	0	0	0	0	256
PER	325	172	255	143	40	0	0	0	0	0	0	0	0	610
FCY	326TO	79	107	45	15	0	0	0	0	0	0	0	0	246
PER	335	188	255	107	35	0	0	0	0	0	0	0	0	585
FCY	336TO	62	89	28	4	2	0	0	0	0	0	0	0	185
PER	345	148	212	66	9	4	0	0	0	0	0	0	0	439
FCY	346TO	65	73	19	2	0	0	0	0	0	0	0	0	159
PER	355	155	174	45	4	0	0	0	0	0	0	0	0	378
	SUM	1682	1611	563	113	11	0	0	0	0	0	0	1	
		4003	3830	1325	260	22	0	0	0	0	0	0	2	

Total No. Observations = 4184
Frequency Calm = 203 Per cent Calm = 4.85
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
April 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	40	34	12	0	0	0	0	0	0	0	0	0	86
PER	5	97	83	29	0	0	0	0	0	0	0	0	0	209
FCY	6TO	42	23	6	0	0	0	0	0	0	0	0	0	71
PER	15	102	56	14	0	0	0	0	0	0	0	0	0	172
FCY	16TO	47	27	3	0	0	0	0	0	0	0	0	0	77
PER	25	114	66	7	0	0	0	0	0	0	0	0	0	187
FCY	26TO	47	22	0	0	0	0	0	0	0	0	0	0	69
PER	35	114	53	0	0	0	0	0	0	0	0	0	0	167
FCY	36TO	40	18	0	0	0	0	0	0	0	0	0	0	58
PER	45	97	44	0	0	0	0	0	0	0	0	0	0	141
FCY	46TO	24	25	5	1	0	0	0	0	0	0	0	0	55
PER	55	58	61	12	2	0	0	0	0	0	0	0	0	133
FCY	56TO	34	30	21	1	0	0	0	0	0	0	0	0	86
PER	65	83	73	51	2	0	0	0	0	0	0	0	0	209
FCY	66TO	41	53	22	0	0	0	0	0	0	0	0	0	116
PER	75	100	129	53	0	0	0	0	0	0	0	0	0	282
FCY	76TO	31	48	18	0	0	0	0	0	0	0	0	0	97
PER	85	75	117	44	0	0	0	0	0	0	0	0	0	236
FCY	86TO	38	60	16	0	0	0	0	0	0	0	0	0	114
PER	95	92	146	39	0	0	0	0	0	0	0	0	0	277
FCY	96TO	55	49	15	0	0	0	0	0	0	0	0	0	119
PER	105	134	119	36	0	0	0	0	0	0	0	0	0	289
FCY	106TO	54	22	0	0	0	0	0	0	0	0	0	0	76
PER	115	132	53	0	0	0	0	0	0	0	0	0	0	185
FCY	116TO	45	13	0	0	0	0	0	0	0	0	0	0	58
PER	125	110	31	0	0	0	0	0	0	0	0	0	0	141
FCY	126TO	47	10	1	0	0	0	0	0	0	0	0	0	58
PER	135	114	24	2	0	0	0	0	0	0	0	0	0	140
FCY	136TC	42	18	0	0	0	0	0	0	0	0	0	0	60
PER	145	102	44	0	0	0	0	0	0	0	0	0	0	146
FCY	146TO	32	41	1	0	0	0	0	0	0	0	0	0	74
PER	155	78	100	2	0	0	0	0	0	0	0	0	0	180
FCY	156TO	35	39	7	0	0	0	0	0	0	0	0	0	81
PER	165	85	95	17	0	0	0	0	0	0	0	0	0	197
FCY	166TO	18	17	12	0	0	0	0	0	0	0	0	0	47
PER	175	44	41	29	0	0	0	0	0	0	0	0	0	114
FCY	176TO	31	38	29	8	0	0	0	0	0	0	0	0	106
PER	185	75	92	70	19	0	0	0	0	0	0	0	0	256
FCY	186TO	38	69	31	5	0	0	0	0	0	0	0	0	143
PER	195	92	168	75	12	0	0	0	0	0	0	0	0	347
FCY	196TO	39	60	23	1	0	0	0	0	0	0	0	0	123
PER	205	95	146	56	2	0	0	0	0	0	0	0	0	299
FCY	206TO	39	47	16	2	0	0	0	0	0	0	0	0	104
PER	215	95	114	39	4	0	0	0	0	0	0	0	0	252
FCY	216TO	33	29	4	1	0	0	0	0	0	0	0	0	67
PER	225	80	70	9	2	0	0	0	0	0	0	0	0	161
FCY	226TO	30	15	11	0	0	0	0	0	0	0	0	0	56
PER	235	73	36	26	0	0	0	0	0	0	0	0	0	135
FCY	236TO	34	13	6	1	1	0	0	0	0	0	0	0	55
PER	245	83	31	14	2	2	0	0	0	0	0	0	0	132
FCY	246TO	36	25	8	3	0	0	0	0	0	0	0	0	72
PER	255	88	61	19	7	0	0	0	0	0	0	0	0	175
FCY	256TO	28	21	9	2	1	1	0	0	0	0	0	0	62
PER	265	68	51	22	4	2	2	0	0	0	0	0	0	149
FCY	266TO	54	21	5	0	1	0	0	0	0	0	0	0	81
PER	275	132	51	12	0	2	0	0	0	0	0	0	0	197
FCY	276TO	57	35	18	2	1	0	0	0	0	0	0	0	113
PER	285	139	85	44	4	2	0	0	0	0	0	0	0	274
FCY	286TO	56	53	41	15	2	0	0	0	0	0	0	0	167
PER	295	136	129	100	36	4	0	0	0	0	0	0	0	405
FCY	296TO	50	73	55	24	3	0	0	0	0	0	0	0	205
PER	305	122	178	134	58	7	0	0	0	0	0	0	0	499
FCY	306TO	42	67	45	12	1	0	0	0	0	0	0	0	167
PER	315	102	163	110	29	2	0	0	0	0	0	0	0	406
FCY	316TO	57	122	60	10	0	0	0	0	0	0	0	0	249
PER	325	139	298	146	24	0	0	0	0	0	0	0	0	607
FCY	326TO	83	191	87	17	0	0	0	0	0	0	0	0	378
PER	335	203	467	212	41	0	0	0	0	0	0	0	0	923
FCY	336TO	67	121	57	9	0	0	0	0	0	0	0	0	254
PER	345	163	295	139	22	0	0	0	0	0	0	0	0	619
FCY	346TO	52	67	23	2	0	0	0	0	0	0	0	0	144
PER	355	127	163	56	4	0	0	0	0	0	0	0	0	350
	SUM	1538	1616	667	116	10	1	0	0	0	0	0	0	
		3743	3933	1618	274	21	2	0	0	0	0	0	0	

Total No. Observations = 4088

Frequency Calm = 140 Per cent Calm = 3.42

FCY = frequency of occurrence

PER = per cent of occurrence of total observations

Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
May 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	53	54	12	0	0	0	0	0	0	0	0	0	119
PER	5	126	128	28	0	0	0	0	0	0	0	0	0	202
FCY	6TO	61	60	13	1	0	0	0	0	0	0	0	0	135
PER	15	145	143	31	2	0	0	0	0	0	0	0	0	321
FCY	16TO	49	27	6	1	0	0	0	0	0	0	0	0	83
PER	25	116	64	14	2	0	0	0	0	0	0	0	0	196
FCY	26TO	45	43	2	0	0	0	0	0	0	0	0	0	90
PER	35	107	102	4	0	0	0	0	0	0	0	0	0	213
FCY	36TO	45	27	0	0	0	0	0	0	0	0	0	0	72
PER	45	107	64	0	0	0	0	0	0	0	0	0	0	171
FCY	46TO	33	27	5	0	0	0	0	0	0	0	0	0	65
PER	55	78	64	11	0	0	0	0	0	0	0	0	0	153
FCY	56TO	29	28	5	1	1	0	0	0	0	0	0	0	64
PER	65	69	66	11	2	2	0	0	0	0	0	0	0	150
FCY	66TO	24	20	7	6	1	0	0	0	0	0	0	0	58
PER	75	57	47	16	14	2	0	0	0	0	0	0	0	136
FCY	76TO	24	15	6	1	1	0	0	0	0	0	0	0	47
PER	85	57	35	14	2	2	0	0	0	0	0	0	0	110
FCY	86TO	36	23	2	0	0	0	0	0	0	0	0	0	61
PER	95	85	54	4	0	0	0	0	0	0	0	0	0	143
FCY	96TO	45	31	5	0	0	0	0	0	0	0	0	0	81
PER	105	107	73	11	0	0	0	0	0	0	0	0	0	191
FCY	106TO	64	32	1	0	0	0	0	0	0	0	0	0	97
PER	115	152	76	2	0	0	0	0	0	0	0	0	0	230
FCY	116TO	48	12	0	0	0	0	0	0	0	0	0	0	60
PER	125	114	28	0	0	0	0	0	0	0	0	0	0	142
FCY	126TO	43	21	0	0	0	0	0	0	0	0	0	0	64
PER	135	102	50	0	0	0	0	0	0	0	0	0	0	152
FCY	136TO	26	25	4	0	0	0	0	0	0	0	0	0	55
PER	145	62	59	9	0	0	0	0	0	0	0	0	0	130
FCY	146TO	37	30	2	0	0	0	0	0	0	0	0	0	69
PER	155	88	71	4	0	0	0	0	0	0	0	0	0	163
FCY	156TO	36	41	1	0	0	0	0	0	0	0	0	0	78
PER	165	85	97	2	0	0	0	0	0	0	0	0	0	184
FCY	166TO	27	39	7	0	0	0	0	0	0	0	0	0	73
PER	175	64	93	16	0	0	0	0	0	0	0	0	0	173
FCY	176TO	45	32	17	0	0	0	0	0	0	0	0	0	94
PER	185	107	76	40	0	0	0	0	0	0	0	0	0	223
FCY	186TO	56	70	26	1	0	0	0	0	0	0	0	0	153
PER	195	133	166	62	2	0	0	0	0	0	0	0	0	363
FCY	196TO	88	102	30	11	1	0	0	0	0	0	0	0	232
PER	205	209	243	71	26	2	0	0	0	0	0	0	0	551
FCY	206TO	70	80	31	12	4	0	0	0	0	0	0	0	197
PER	215	166	159	73	28	9	0	0	0	0	0	0	0	466
FCY	216TO	62	43	13	5	0	0	0	0	0	0	0	0	123
PER	225	147	102	31	11	0	0	0	0	0	0	0	0	291
FCY	226TO	48	42	11	1	0	0	0	0	0	0	0	0	102
PER	235	114	100	26	2	0	0	0	0	0	0	0	0	242
FCY	236TO	58	35	8	0	0	0	0	0	0	0	0	0	101
PER	245	138	83	19	0	0	0	0	0	0	0	0	0	240
FCY	246TO	54	41	5	0	0	0	0	0	0	0	0	0	100
PER	255	128	57	11	0	0	0	0	0	0	0	0	0	236
FCY	256TO	59	33	11	1	0	0	0	0	0	0	0	0	104
PER	265	140	78	26	2	0	0	0	0	0	0	0	0	246
FCY	266TO	44	29	10	1	0	0	0	0	0	0	0	0	84
PER	275	104	69	23	2	0	0	0	0	0	0	0	0	198
FCY	276TO	55	51	9	1	0	0	0	0	0	0	0	0	116
PER	285	131	121	21	2	0	0	0	0	0	0	0	0	275
FCY	286TO	72	63	17	1	0	0	0	0	0	0	0	0	153
PER	295	171	150	40	2	0	0	0	0	0	0	0	0	363
FCY	296TO	59	78	23	0	0	0	0	0	0	0	0	0	160
PER	305	140	186	54	0	0	0	0	0	0	0	0	0	380
FCY	306TO	37	66	31	0	0	0	0	0	0	0	0	0	134
PER	315	88	157	73	0	0	0	0	0	0	0	0	0	318
FCY	316TO	47	79	52	3	0	0	0	0	0	0	0	0	181
PER	325	112	188	124	7	0	0	0	0	0	0	0	0	431
FCY	326TO	76	117	49	0	0	0	0	0	0	0	0	0	242
PER	335	181	279	116	0	0	0	0	0	0	0	0	0	576
FCY	336TO	77	91	20	0	0	0	0	0	0	0	0	0	188
PER	345	183	217	47	0	0	0	0	0	0	0	0	0	447
FCY	346TO	60	60	17	0	0	0	0	0	0	0	0	0	137
PER	355	143	143	40	0	0	0	0	0	0	0	0	0	326
	SUM	1792	1667	458	47	8	0	0	0	0	0	0	0	
		4256	3959	1074	106	17	0	0	0	0	0	0	0	

Total No. Observations = 4192
Frequency Calm = 220 Per cent Calm = 5.24
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
June 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1- 5	6- 10	11- 15	16- 20	21- 25	26- 30	31- 35	36- 40	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TO	26	48	10	0	0	0	0	0	0	0	0	0	84
PER	5	91	168	35	0	0	0	0	0	0	0	0	0	294
FCY	6TO	37	38	1	0	0	0	0	0	0	0	0	0	76
PER	15	129	133	3	0	0	0	0	0	0	0	0	0	265
FCY	16TO	52	41	1	0	0	0	0	0	0	0	0	0	94
PER	25	182	143	3	0	0	0	0	0	0	0	0	0	328
FCY	26TO	32	9	0	0	0	0	0	0	0	0	0	0	41
PER	35	112	31	0	0	0	0	0	0	0	0	0	0	143
FCY	36TO	21	18	1	0	0	0	0	0	0	0	0	0	40
PER	45	73	63	3	0	0	0	0	0	0	0	0	0	139
FCY	46TO	14	16	4	0	0	0	0	0	0	0	0	0	34
PER	55	49	56	14	0	0	0	0	0	0	0	0	0	119
FCY	56TO	16	32	17	0	0	0	0	0	0	0	0	0	65
PER	65	56	112	59	0	0	0	0	0	0	0	0	0	227
FCY	66TO	25	17	8	0	0	0	0	0	0	0	0	0	50
PER	75	87	59	28	0	0	0	0	0	0	0	0	0	174
FCY	76TO	11	10	0	0	0	0	0	0	0	0	0	0	21
PER	85	38	35	0	0	0	0	0	0	0	0	0	0	73
FCY	86TO	10	13	1	0	0	0	0	0	0	0	0	0	24
PER	95	35	45	3	0	0	0	0	0	0	0	0	0	83
FCY	96TO	14	12	1	0	0	0	0	0	0	0	0	0	27
PER	105	49	42	3	0	0	0	0	0	0	0	0	0	94
FCY	106TO	14	10	0	0	0	0	0	0	0	0	0	0	24
PER	115	49	35	0	0	0	0	0	0	0	0	0	0	84
FCY	116TO	4	1	1	0	0	0	0	0	0	0	0	0	6
PER	125	14	3	3	0	0	0	0	0	0	0	0	0	20
FCY	126TO	6	1	0	0	0	0	0	0	0	0	0	0	7
PER	135	21	3	0	0	0	0	0	0	0	0	0	0	24
FCY	136TO	6	2	0	0	0	0	0	0	0	0	0	0	8
PER	145	21	7	0	0	0	0	0	0	0	0	0	0	28
FCY	146TO	7	1	0	0	0	0	0	0	0	0	0	0	8
PER	155	24	3	0	0	0	0	0	0	0	0	0	0	27
FCY	156TO	20	8	0	0	0	0	0	0	0	0	0	0	28
PER	165	70	28	0	0	0	0	0	0	0	0	0	0	98
FCY	166TO	20	0	0	0	0	0	0	0	0	0	0	0	20
PER	175	70	0	0	0	0	0	0	0	0	0	0	0	70
FCY	176TO	31	4	0	0	0	0	0	0	0	0	0	0	35
PER	185	108	14	0	0	0	0	0	0	0	0	0	0	122
FCY	186TO	58	46	7	0	0	0	0	0	0	0	0	0	111
PER	195	203	161	24	0	0	0	0	0	0	0	0	0	388
FCY	196TO	77	87	11	0	0	0	0	0	0	0	0	0	175
PER	205	270	305	38	0	0	0	0	0	0	0	0	0	613
FCY	206TO	61	108	21	1	0	0	0	0	0	0	0	0	191
PER	215	214	378	73	3	0	0	0	0	0	0	0	0	668
FCY	216TO	69	82	15	0	0	0	0	0	0	0	0	0	166
PER	225	242	287	52	0	0	0	0	0	0	0	0	0	581
FCY	226TO	66	88	12	1	0	0	0	0	0	0	0	0	167
PER	235	231	308	42	3	0	0	0	0	0	0	0	0	584
FCY	236TO	75	69	10	0	0	0	0	0	0	0	0	0	154
PER	245	263	242	35	0	0	0	0	0	0	0	0	0	540
FCY	246TO	64	34	1	0	0	0	0	0	0	0	0	0	99
PER	255	224	119	3	0	0	0	0	0	0	0	0	0	346
FCY	256TO	67	28	0	0	0	0	0	0	0	0	0	0	95
PER	265	235	98	0	0	0	0	0	0	0	0	0	0	333
FCY	266TO	49	25	1	0	0	0	0	0	0	0	0	0	75
PER	275	171	87	3	0	0	0	0	0	0	0	0	0	261
FCY	276TO	55	21	2	0	0	0	0	0	0	0	0	0	78
PER	285	192	73	7	0	0	0	0	0	0	0	0	0	272
FCY	286TO	64	21	0	0	0	0	0	0	0	0	0	0	85
PER	295	224	73	0	0	0	0	0	0	0	0	0	0	297
FCY	296TO	60	19	3	0	0	0	0	0	0	0	0	0	82
PER	305	210	66	10	0	0	0	0	0	0	0	0	0	286
FCY	306TO	71	21	3	0	0	0	0	0	0	0	0	0	95
PER	315	249	73	10	0	0	0	0	0	0	0	0	0	332
FCY	316TO	87	55	6	0	0	0	0	0	0	0	0	0	148
PER	325	305	192	21	0	0	0	0	0	0	0	0	0	518
FCY	326TO	66	69	0	0	0	0	0	0	0	0	0	0	135
PER	335	231	242	0	0	0	0	0	0	0	0	0	0	473
FCY	336TO	52	51	5	0	0	0	0	0	0	0	0	0	108
PER	345	182	178	17	0	0	0	0	0	0	0	0	0	377
FCY	346TO	38	40	8	0	0	0	0	0	0	0	0	0	86
PER	355	133	140	28	0	0	0	0	0	0	0	0	0	301
	SUM	1445	1145	150	2	0	0	0	0	0	0	0	0	
		5057	4002	517	6	0	0	0	0	0	0	0	0	

Total No. Observations = 2850
Frequency Calm = 108 Per cent Calm = 3.78
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
July 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1- 5	6- 10	11- 15	16- 20	21- 25	26- 30	31- 35	36- 40	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TO	52	27	5	0	0	0	0	0	0	0	0	0	84
PER	5	182	94	17	0	0	0	0	0	0	0	0	0	293
FCY	6TO	48	25	5	0	0	0	0	0	0	0	0	0	78
PER	15	168	87	17	0	0	0	0	0	0	0	0	0	272
FCY	16TO	39	14	0	0	0	0	0	0	0	0	0	0	53
PER	25	137	49	0	0	0	0	0	0	0	0	0	0	186
FCY	26TO	33	12	0	0	0	0	0	0	0	0	0	0	45
PER	35	116	42	0	0	0	0	0	0	0	0	0	0	158
FCY	36TO	37	8	0	0	0	0	0	0	0	0	0	0	45
PER	45	130	28	0	0	0	0	0	0	0	0	0	0	158
FCY	46TO	36	8	0	0	0	0	0	0	0	0	0	0	44
PER	55	126	28	0	0	0	0	0	0	0	0	0	0	154
FCY	56TO	26	10	0	0	0	0	0	0	0	0	0	0	36
PER	65	91	35	0	0	0	0	0	0	0	0	0	0	126
FCY	66TO	22	10	0	0	0	0	0	0	0	0	0	0	32
PER	75	77	35	0	0	0	0	0	0	0	0	0	0	112
FCY	76TO	23	8	0	0	0	0	0	0	0	0	0	0	31
PER	85	80	28	0	0	0	0	0	0	0	0	0	0	108
FCY	86TO	10	2	0	0	0	0	0	0	0	0	0	0	12
PER	95	35	7	0	0	0	0	0	0	0	0	0	0	42
FCY	96TO	12	3	0	0	0	0	0	0	0	0	0	0	15
PER	105	42	10	0	0	0	0	0	0	0	0	0	0	52
FCY	106TO	5	5	0	0	0	0	0	0	0	0	0	0	10
PER	115	17	17	0	0	0	0	0	0	0	0	0	0	34
FCY	116TO	14	0	0	0	0	0	0	0	0	0	0	0	14
PER	125	49	0	0	0	0	0	0	0	0	0	0	0	49
FCY	126TO	13	0	0	0	0	0	0	0	0	0	0	0	13
PER	135	45	0	0	0	0	0	0	0	0	0	0	0	45
FCY	136TO	22	4	0	0	0	0	0	0	0	0	0	0	26
PER	145	77	14	0	0	0	0	0	0	0	0	0	0	91
FCY	146TO	27	22	4	0	0	0	0	0	0	0	0	0	53
PER	155	94	77	14	0	0	0	0	0	0	0	0	0	185
FCY	156TO	30	52	4	0	0	0	0	0	0	0	0	0	86
PER	165	105	182	14	0	0	0	0	0	0	0	0	0	301
FCY	166TO	41	29	4	0	0	0	0	0	0	0	0	0	74
PER	175	144	102	14	0	0	0	0	0	0	0	0	0	260
FCY	176TO	44	28	8	0	0	0	0	0	0	0	0	0	80
PER	185	154	98	28	0	0	0	0	0	0	0	0	0	280
FCY	186TO	70	90	16	0	0	0	0	0	0	0	0	0	176
PER	195	246	316	56	0	0	0	0	0	0	0	0	0	618
FCY	196TO	56	84	13	1	0	0	0	0	0	0	0	0	154
PER	205	196	295	45	3	0	0	0	0	0	0	0	0	539
FCY	206TO	52	90	22	1	0	0	0	0	0	0	0	0	165
PER	215	182	316	77	3	0	0	0	0	0	0	0	0	578
FCY	216TO	50	74	8	0	0	0	0	0	0	0	0	0	132
PER	225	175	260	28	0	0	0	0	0	0	0	0	0	463
FCY	226TO	46	60	0	0	0	0	0	0	0	0	0	0	106
PER	235	161	211	0	0	0	0	0	0	0	0	0	0	372
FCY	236TO	71	57	2	0	0	0	0	0	0	0	0	0	130
PER	245	249	200	7	0	0	0	0	0	0	0	0	0	456
FCY	246TO	62	31	0	0	0	0	0	0	0	0	0	0	93
PER	255	218	109	0	0	0	0	0	0	0	0	0	0	327
FCY	256TO	56	19	0	0	0	0	0	0	0	0	0	0	75
PER	265	196	66	0	0	0	0	0	0	0	0	0	0	262
FCY	266TO	69	12	0	0	0	0	0	0	0	0	0	0	81
PER	275	242	42	0	0	0	0	0	0	0	0	0	0	284
FCY	276TO	55	12	0	0	0	0	0	0	0	0	0	0	67
PER	285	193	42	0	0	0	0	0	0	0	0	0	0	235
FCY	286TO	52	19	0	1	0	0	0	0	0	0	0	0	72
PER	295	182	66	0	3	0	0	0	0	0	0	0	0	251
FCY	296TO	54	18	0	0	0	0	0	0	0	0	0	0	72
PER	305	189	63	0	0	0	0	0	0	0	0	0	0	252
FCY	306TO	52	11	0	0	0	0	0	0	0	0	0	0	63
PER	315	182	38	0	0	0	0	0	0	0	0	0	0	220
FCY	316TO	54	25	0	0	0	0	0	0	0	0	0	0	79
PER	325	189	87	0	0	0	0	0	0	0	0	0	0	276
FCY	326TO	81	97	0	0	0	0	0	0	0	0	0	0	178
PER	335	284	341	0	0	0	0	0	0	0	0	0	0	625
FCY	336TO	78	40	1	0	0	0	0	0	0	0	0	0	119
PER	345	274	140	3	0	0	0	0	0	0	0	0	0	417
FCY	346TO	58	33	1	0	0	0	0	0	0	0	0	0	92
PER	355	204	116	3	0	0	0	0	0	0	0	0	0	323
SUM		1550	1039	91	3	0	0	0	0	0	0	0	0	
		5421	3641	323	9	0	0	0	0	0	0	0	0	

Total No. Observations = 2843
Frequency Calm = 158 Per cent Calm = 5.55
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
August 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	31	5	0	0	0	0	0	0	0	0	0	0	36
PER	5	113	18	0	0	0	0	0	0	0	0	0	0	131
FCY	6TO	23	4	0	0	0	0	0	0	0	0	0	0	27
PER	15	84	14	0	0	0	0	0	0	0	0	0	0	98
FCY	16TO	22	3	0	0	0	0	0	0	0	0	0	0	25
PER	25	80	10	0	0	0	0	0	0	0	0	0	0	90
FCY	26TO	14	2	0	0	0	0	0	0	0	0	0	0	16
PER	35	51	7	0	0	0	0	0	0	0	0	0	0	58
FCY	36TO	12	0	0	0	0	0	0	0	0	0	0	0	12
PER	45	43	0	0	0	0	0	0	0	0	0	0	0	43
FCY	46TO	12	1	0	0	0	0	0	0	0	0	0	0	13
PER	55	43	3	0	0	0	0	0	0	0	0	0	0	46
FCY	56TO	13	4	0	0	0	0	0	0	0	0	0	0	17
PER	65	47	14.	0	0	0	0	0	0	0	0	0	0	61
FCY	66TO	12	0	0	0	0	0	0	0	0	0	0	0	12
PER	75	43	0	0	0	0	0	0	0	0	0	0	0	43
FCY	76TO	18	1	0	0	0	0	0	0	0	0	0	0	19
PER	85	65	3	0	0	0	0	0	0	0	0	0	0	68
FCY	86TO	24	0	0	0	0	0	0	0	0	0	0	0	24
PER	95	87	0	0	0	0	0	0	0	0	0	0	0	87
FCY	96TO	23	6	0	0	0	0	0	0	0	0	0	0	29
PER	105	84	21	0	0	0	0	0	0	0	0	0	0	105
FCY	106TO	27	6	0	0	0	0	0	0	0	0	0	0	33
PER	115	98	21	0	0	0	0	0	0	0	0	0	0	119
FCY	116TO	20	2	0	0	0	0	0	0	0	0	0	0	22
PER	125	73	7	0	0	0	0	0	0	0	0	0	0	80
FCY	126TO	32	6	0	0	0	0	0	0	0	0	0	0	38
PER	135	116	21	0	0	0	0	0	0	0	0	0	0	137
FCY	136TO	30	22	2	0	0	0	0	0	0	0	0	0	54
PER	145	109	80	7	0	0	0	0	0	0	0	0	0	196
FCY	146TO	54	28	4	0	0	0	0	0	0	0	0	0	86
PER	155	197	102	14	0	0	0	0	0	0	0	0	0	313
FCY	156TO	29	45	6	0	0	0	0	0	0	0	0	0	80
PER	165	105	164	21	0	0	0	0	0	0	0	0	0	290
FCY	166TO	36	21	3	0	0	0	0	0	0	0	0	0	60
PER	175	131	76	10	0	0	0	0	0	0	0	0	0	217
FCY	176TO	58	50	6	0	0	0	0	0	0	0	0	0	114
PER	185	211	182	21	0	0	0	0	0	0	0	0	0	414
FCY	186TO	64	83	17	0	0	0	0	0	0	0	0	0	164
PER	195	233	303	62	0	0	0	0	0	0	0	0	0	598
FCY	196TO	69	98	26	0	0	0	0	0	0	0	0	0	193
PER	205	252	358	94	0	0	0	0	0	0	0	0	0	704
FCY	206TO	67	71	19	0	0	0	0	0	0	0	0	0	157
PER	215	244	259	69	0	0	0	0	0	0	0	0	0	572
FCY	216TO	52	37	2	1	0	0	0	0	0	0	0	0	92
PER	225	189	135	7	3	0	0	0	0	0	0	0	0	334
FCY	226TO	41	24	1	0	0	0	0	0	0	0	0	0	66
PER	235	149	87	3	0	0	0	0	0	0	0	0	0	239
FCY	236TO	62	42	0	0	0	0	0	0	0	0	0	0	104
PER	245	226	153	0	0	0	0	0	0	0	0	0	0	379
FCY	246TO	47	19	1	0	0	0	0	0	0	0	0	0	67
PER	255	171	69	3	0	0	0	0	0	0	0	0	0	243
FCY	256TO	41	27	1	0	0	0	0	0	0	0	0	0	69
PER	265	149	98	3	0	0	0	0	0	0	0	0	0	250
FCY	266TO	55	21	0	0	0	0	0	0	0	0	0	0	76
PER	275	200	76	0	0	0	0	0	0	0	0	0	0	276
FCY	276TO	73	38	1	0	0	0	0	0	0	0	0	0	112
PER	285	266	138	3	0	0	0	0	0	0	0	0	0	407
FCY	286TO	76	36	0	0	0	0	0	0	0	0	0	0	112
PER	295	277	131	0	0	0	0	0	0	0	0	0	0	408
FCY	296TO	62	29	4	1	0	0	0	0	0	0	0	0	96
PER	305	226	105	14	3	0	0	0	0	0	0	0	0	348
FCY	306TO	73	22	5	0	0	0	0	0	0	0	0	0	100
PER	315	266	80	18	0	0	0	0	0	0	0	0	0	364
FCY	316TO	81	48	5	0	0	0	0	0	0	0	0	0	134
PER	325	295	175	18	0	0	0	0	0	0	0	0	0	488
FCY	326TO	79	64	5	0	0	0	0	0	0	0	0	0	148
PER	335	288	233	18	0	0	0	0	0	0	0	0	0	539
FCY	336TO	52	45	1	0	0	0	0	0	0	0	0	0	98
PER	345	189	164	3	0	0	0	0	0	0	0	0	0	356
FCY	346TO	41	24	1	0	0	0	0	0	0	0	0	0	66
PER	355	149	87	3	0	0	0	0	0	0	0	0	0	239
	SUM	1525	934	110	2	0	0	0	0	0	0	0	0	
		5549	3394	391	6	0	0	0	0	0	0	0	0	

Total No. Observations = 2737
Frequency Calm = 166 Per cent Calm = 6.06
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
September 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	59	16	0	0	0	0	0	0	0	0	0	0	75
PER	5	218	59	0	0	0	0	0	0	0	0	0	0	277
FCY	6TO	53	24	0	0	0	0	0	0	0	0	0	0	77
PER	15	195	88	0	0	0	0	0	0	0	0	0	0	283
FCY	16TO	44	20	0	0	0	0	0	0	0	0	0	0	64
PER	25	162	73	0	0	0	0	0	0	0	0	0	0	235
FCY	26TO	40	11	0	0	0	0	0	0	0	0	0	0	51
PER	35	147	40	0	0	0	0	0	0	0	0	0	0	187
FCY	36TO	34	7	1	0	0	0	0	0	0	0	0	0	42
PER	45	125	25	3	0	0	0	0	0	0	0	0	0	153
FCY	46TO	31	10	1	0	0	0	0	0	0	0	0	0	42
PER	55	114	36	3	0	0	0	0	0	0	0	0	0	153
FCY	56TO	29	41	7	1	0	0	0	0	0	0	0	0	78
PER	65	107	151	25	3	0	0	0	0	0	0	0	0	286
FCY	66TO	30	53	35	2	0	0	0	0	0	0	0	0	120
PER	75	110	195	129	7	0	0	0	0	0	0	0	0	441
FCY	76TO	45	43	8	0	0	0	0	0	0	0	0	0	96
PER	85	166	158	29	0	0	0	0	0	0	0	0	0	353
FCY	86TO	39	38	0	0	0	0	0	0	0	0	0	0	77
PER	95	144	140	0	0	0	0	0	0	0	0	0	0	284
FCY	96TO	40	30	0	0	0	0	0	0	0	0	0	0	70
PER	105	147	110	0	0	0	0	0	0	0	0	0	0	257
FCY	106TO	43	8	0	0	0	0	0	0	0	0	0	0	51
PER	115	158	29	0	0	0	0	0	0	0	0	0	0	187
FCY	116TO	41	2	0	0	0	0	0	0	0	0	0	0	43
PER	125	151	7	0	0	0	0	0	0	0	0	0	0	158
FCY	126TO	30	10	0	0	0	0	0	0	0	0	0	0	40
PER	135	110	36	0	0	0	0	0	0	0	0	0	0	146
FCY	136TO	29	14	1	0	0	0	0	0	0	0	0	0	44
PER	145	107	51	3	0	0	0	0	0	0	0	0	0	161
FCY	146TO	28	12	0	0	0	0	0	0	0	0	0	0	40
PER	155	103	44	0	0	0	0	0	0	0	0	0	0	147
FCY	156TO	19	10	0	0	0	0	0	0	0	0	0	0	29
PER	165	70	36	0	0	0	0	0	0	0	0	0	0	106
FCY	166TO	21	18	2	0	0	0	0	0	0	0	0	0	41
PER	175	77	66	7	0	0	0	0	0	0	0	0	0	150
FCY	176TO	22	18	5	1	0	0	0	0	0	0	0	0	46
PER	185	81	66	18	3	0	0	0	0	0	0	0	0	168
FCY	186TO	27	55	10	8	0	0	0	0	0	0	0	0	100
PER	195	99	203	36	29	0	0	0	0	0	0	0	0	367
FCY	196TO	41	49	3	4	0	0	0	0	0	0	0	0	97
PER	205	151	181	11	14	0	0	0	0	0	0	0	0	357
FCY	206TO	22	37	0	0	0	0	0	0	0	0	0	0	59
PER	215	81	136	0	0	0	0	0	0	0	0	0	0	217
FCY	216TO	19	18	1	0	0	0	0	0	0	0	0	0	38
PER	225	70	66	3	0	0	0	0	0	0	0	0	0	139
FCY	226TO	24	15	0	1	0	0	0	0	0	0	0	0	40
PER	235	88	55	0	3	0	0	0	0	0	0	0	0	146
FCY	236TO	24	6	0	0	0	0	0	0	0	0	0	0	30
PER	245	88	22	0	0	0	0	0	0	0	0	0	0	110
FCY	246TO	43	13	0	0	0	0	0	0	0	0	0	0	56
PER	255	158	48	0	0	0	0	0	0	0	0	0	0	206
FCY	256TO	35	9	2	0	0	0	0	0	0	0	0	0	46
PER	265	129	33	7	0	0	0	0	0	0	0	0	0	169
FCY	266TO	47	24	4	0	0	0	0	0	0	0	0	0	75
PER	275	173	88	14	0	0	0	0	0	0	0	0	0	275
FCY	276TO	48	24	2	0	0	0	0	0	0	0	0	0	74
PER	285	177	88	7	0	0	0	0	0	0	0	0	0	272
FCY	286TO	49	28	2	0	0	0	0	0	0	0	0	0	79
PER	295	181	103	7	0	0	0	0	0	0	0	0	0	291
FCY	296TO	74	17	2	0	0	0	0	0	0	0	0	0	93
PER	305	273	62	7	0	0	0	0	0	0	0	0	0	342
FCY	306TO	70	11	1	0	0	0	0	0	0	0	0	0	82
PER	315	258	40	3	0	0	0	0	0	0	0	0	0	301
FCY	316TO	73	78	2	0	0	0	0	0	0	0	0	0	153
PER	325	269	288	7	0	0	0	0	0	0	0	0	0	564
FCY	326TO	104	99	2	0	0	0	0	0	1	0	0	0	206
PER	335	384	365	7	0	0	0	0	0	3	0	0	0	759
FCY	336TO	77	49	3	0	0	0	0	0	0	0	0	0	129
PER	345	284	181	11	0	0	0	0	0	0	0	0	0	476
FCY	346TO	68	21	5	0	0	0	0	0	0	0	0	0	94
PER	355	251	77	18	0	0	0	0	0	0	0	0	0	346
	SUM	1522	938	99	17	0	0	0	0	1	0	0	0	
		5606	3466	355	59	0	0	0	0	3	0	0	0	

Total No. Observations = 2706
Frequency Calm = 129 Per cent Calm = 4.76
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
October 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1- 5	6- 10	11- 15	16- 20	21- 25	26- 30	31- 35	36- 40	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TO	31	13	0	0	0	0	0	0	0	0	0	0	44
PER	5	111	44	0	0	0	0	0	0	0	0	0	0	157
FCY	6TO	20	19	0	0	0	0	0	0	0	0	0	0	39
PER	15	71	68	0	0	0	0	0	0	0	0	0	0	139
FCY	16TO	19	16	0	0	0	0	0	0	0	0	0	0	35
PER	25	68	57	0	0	0	0	0	0	0	0	0	0	125
FCY	26TO	23	4	0	0	0	0	0	0	0	0	0	0	27
PER	35	82	14	0	0	0	0	0	0	0	0	0	0	96
FCY	36TO	15	2	0	0	0	0	0	0	0	0	0	0	17
PER	45	53	7	0	0	0	0	0	0	0	0	0	0	60
FCY	46TO	14	2	0	0	0	0	0	0	0	0	0	0	16
PER	55	50	7	0	0	0	0	0	0	0	0	0	0	57
FCY	56TO	18	11	0	0	0	0	0	0	0	0	0	0	29
PER	65	64	39	0	0	0	0	0	0	0	0	0	0	103
FCY	66TO	15	10	0	0	0	0	0	0	0	0	0	0	25
PER	75	53	35	0	0	0	0	0	0	0	0	0	0	88
FCY	76TO	9	5	0	0	0	0	0	0	0	0	0	0	14
PER	85	32	17	0	0	0	0	0	0	0	0	0	0	49
FCY	86TO	7	1	0	0	0	0	0	0	0	0	0	0	8
PER	95	25	3	0	0	0	0	0	0	0	0	0	0	28
FCY	96TO	16	1	0	0	0	0	0	0	0	0	0	0	17
PER	105	57	3	0	0	0	0	0	0	0	0	0	0	60
FCY	106TO	12	4	3	0	0	0	0	0	0	0	0	0	19
PER	115	42	14	10	0	0	0	0	0	0	0	0	0	66
FCY	116TO	13	5	4	0	0	0	0	0	0	0	0	0	22
PER	125	46	17	14	0	0	0	0	0	0	0	0	0	77
FCY	126TO	18	6	2	0	0	0	0	0	0	0	0	0	26
PER	135	64	21	7	0	0	0	0	0	0	0	0	0	92
FCY	136TO	17	6	2	0	0	0	0	0	0	0	0	0	25
PER	145	60	21	7	0	0	0	0	0	0	0	0	0	88
FCY	146TO	18	18	5	0	0	0	0	0	0	0	0	0	41
PER	155	64	64	17	0	0	0	0	0	0	0	0	0	145
FCY	156TO	18	11	1	0	0	0	0	0	0	0	0	0	30
PER	165	64	39	3	0	0	0	0	0	0	0	0	0	106
FCY	166TO	22	4	4	0	0	0	0	0	0	0	0	0	30
PER	175	78	14	14	0	0	0	0	0	0	0	0	0	106
FCY	176TO	34	9	10	2	0	0	0	0	0	0	0	0	-55
PER	185	121	32	35	7	0	0	0	0	0	0	0	0	195
FCY	186TO	44	34	23	5	0	0	0	0	0	0	0	0	106
PER	195	157	121	82	17	0	0	0	0	0	0	0	0	377
FCY	196TO	42	45	32	6	0	0	0	0	0	0	0	0	125
PER	205	150	161	114	21	0	0	0	0	0	0	0	0	446
FCY	206TO	36	65	22	3	0	0	0	0	0	0	0	0	126
PER	215	128	232	78	10	0	0	0	0	0	0	0	0	448
FCY	216TO	39	47	4	1	0	0	0	0	0	0	0	0	91
PER	225	139	168	14	3	0	0	0	0	0	0	0	0	324
FCY	226TO	45	48	8	1	0	0	0	0	0	0	0	0	102
PER	235	161	171	28	3	0	0	0	0	0	0	0	0	363
FCY	236TO	50	48	11	0	0	0	0	0	0	0	0	0	109
PER	245	179	171	39	0	0	0	0	0	0	0	0	0	389
FCY	246TO	60	32	8	0	0	0	0	0	0	0	0	0	100
PER	255	214	114	28	0	0	0	0	0	0	0	0	0	356
FCY	256TO	60	30	1	0	0	0	0	0	0	0	0	0	91
PER	265	214	107	3	0	0	0	0	0	0	0	0	0	324
FCY	266TO	45	15	1	0	0	0	0	0	0	0	0	0	61
PER	275	161	53	3	0	0	0	0	0	0	0	0	0	217
FCY	276TO	68	24	6	1	0	0	0	0	0	0	0	0	99
PER	285	243	85	21	3	0	0	0	0	0	0	0	0	352
FCY	286TO	64	48	9	1	0	0	0	0	0	0	0	0	122
PER	295	229	171	32	3	0	0	0	0	0	0	0	0	435
FCY	296TO	82	73	26	3	0	0	0	0	0	0	0	0	184
PER	305	293	261	93	10	0	0	0	0	0	0	0	0	657
FCY	306TO	93	91	49	8	1	0	0	0	0	0	0	0	242
PER	315	333	326	175	28	3	0	0	0	0	0	0	0	865
FCY	316TO	77	104	36	4	0	0	0	0	0	0	0	0	221
PER	325	275	372	128	14	0	0	0	0	0	0	0	0	789
FCY	326TO	70	73	23	3	0	0	0	0	0	0	0	0	169
PER	335	250	261	82	10	0	0	0	0	0	0	0	0	603
FCY	336TO	42	42	8	0	0	0	0	0	0	0	0	0	92
PER	345	150	150	28	0	0	0	0	0	0	0	0	0	328
FCY	346TO	22	24	4	0	0	0	0	0	0	0	0	0	50
PER	355	78	85	14	0	0	0	0	0	0	0	0	0	177
	SUM	1278	990	302	38	1	0	0	0	0	0	0	0	
		4559	3527	1069	129	3	0	0	0	0	0	0	0	

Total No. Observations = 2791
Frequency Calm = 182 Per cent Calm = 6.52
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
November 1964-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1- 5	6- 10	11- 15	16- 20	21- 25	26- 30	31- 35	36- 40	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TO	65	31	2	0	0	0	0	0	0	0	0	0	98
PER	5	152	72	4	0	0	0	0	0	0	0	0	0	228
FCY	6TO	46	20	0	0	0	0	0	0	0	0	0	0	66
PER	15	107	46	0	0	0	0	0	0	0	0	0	0	153
FCY	16TO	38	11	0	0	0	0	0	0	0	0	0	0	49
PER	25	89	25	0	0	0	0	0	0	0	0	0	0	114
FCY	26TO	44	11	0	0	0	0	0	0	0	0	0	0	55
PER	35	103	25	0	0	0	0	0	0	0	0	0	0	128
FCY	36TO	23	4	0	0	0	0	0	0	0	0	0	0	27
PER	45	53	9	0	0	0	0	0	0	0	0	0	0	62
FCY	46TO	22	5	0	0	0	0	0	0	0	0	0	0	27
PER	55	51	11	0	0	0	0	0	0	0	0	0	0	62
FCY	56TO	29	8	0	0	0	0	0	0	0	0	0	0	37
PER	65	68	18	0	0	0	0	0	0	0	0	0	0	86
FCY	66TO	30	16	1	0	0	0	0	0	0	0	0	0	47
PER	75	70	37	2	0	0	0	0	0	0	0	0	0	109
FCY	76TO	35	27	0	0	0	0	0	0	0	0	0	0	62
PER	85	82	63	0	0	0	0	0	0	0	0	0	0	145
FCY	86TO	48	19	3	1	0	0	0	0	0	0	0	0	71
PER	95	112	44	7	2	0	0	0	0	0	0	0	0	165
FCY	96TO	59	30	7	0	0	0	0	0	0	0	0	0	96
PER	105	138	70	16	0	0	0	0	0	0	0	0	0	224
FCY	106TO	48	19	9	0	0	0	0	0	0	0	0	0	76
PER	115	112	44	21	0	0	0	0	0	0	0	0	0	177
FCY	116TO	20	11	2	0	0	0	0	0	0	0	0	0	33
PER	125	93	25	4	0	0	0	0	0	0	0	0	0	122
FCY	126TO	44	10	5	2	0	0	0	0	0	0	0	0	61
PER	135	103	23	11	4	0	0	0	0	0	0	0	0	141
FCY	136TO	26	16	3	5	0	0	0	0	0	0	0	0	50
PER	145	60	37	7	11	0	0	0	0	0	0	0	0	115
FCY	146TO	23	15	2	1	0	0	0	0	0	0	0	0	41
PER	155	53	35	4	2	0	0	0	0	0	0	0	0	94
FCY	156TO	26	27	3	0	0	0	0	0	0	0	0	0	56
PER	165	60	63	7	0	0	0	0	0	0	0	0	0	130
FCY	166TO	29	13	12	0	0	0	0	0	0	0	0	0	54
PER	175	68	30	28	0	0	0	0	0	0	0	0	0	126
FCY	176TO	52	45	21	2	0	0	0	0	0	0	0	0	120
PER	185	121	105	49	4	0	0	0	0	0	0	0	0	279
FCY	186TO	86	140	30	5	1	0	0	0	0	0	0	0	262
PER	195	201	328	70	11	2	0	0	0	0	0	0	0	612
FCY	196TO	72	91	18	3	0	0	0	0	0	0	0	0	184
PER	205	168	213	42	7	0	0	0	0	0	0	0	0	430
FCY	206TO	50	53	28	5	0	0	0	0	0	0	0	0	136
PER	215	117	124	65	11	0	0	0	0	0	0	0	0	317
FCY	216TO	63	53	18	0	0	0	0	0	0	0	0	0	134
PER	225	147	124	42	0	0	0	0	0	0	0	0	0	313
FCY	226TO	57	44	14	3	0	0	0	0	0	0	0	0	118
PER	235	133	103	32	7	0	0	0	0	0	0	0	0	275
FCY	236TO	46	38	19	1	0	0	0	0	0	0	0	0	104
PER	245	107	89	44	2	0	0	0	0	0	0	0	0	242
FCY	246TO	52	37	17	3	0	0	0	0	0	0	0	0	109
PER	255	121	86	39	7	0	0	0	0	0	0	0	0	253
FCY	256TO	52	37	20	5	0	0	0	0	0	0	0	0	114
PER	265	121	86	46	11	0	0	0	0	0	0	0	0	264
FCY	266TO	60	50	19	7	0	0	0	0	0	0	0	0	136
PER	275	140	117	44	16	0	0	0	0	0	0	0	0	317
FCY	276TO	80	56	21	5	0	0	0	0	0	0	0	0	162
PER	285	187	131	49	11	0	0	0	0	0	0	0	0	378
FCY	286TO	71	76	29	6	1	0	0	0	0	0	0	0	183
PER	295	166	178	68	14	2	0	0	0	0	0	0	0	428
FCY	296TO	63	81	43	9	0	0	0	0	0	0	0	0	196
PER	305	147	189	100	21	0	0	0	0	0	0	0	0	457
FCY	306TO	77	101	39	19	2	0	0	0	0	0	0	0	238
PER	315	180	236	91	44	4	0	0	0	0	0	0	0	555
FCY	316TO	94	141	34	10	3	0	0	0	0	0	0	0	282
PER	325	220	330	79	23	7	0	0	0	0	0	0	0	659
FCY	326TO	96	114	33	7	0	0	0	0	0	0	0	0	250
PER	335	225	267	77	16	0	0	0	0	0	0	0	0	585
FCY	336TO	72	79	30	2	1	0	0	0	0	0	0	0	184
PER	345	168	185	70	4	2	0	0	0	0	0	0	0	429
FCY	346TO	64	47	8	1	0	0	0	0	0	0	0	0	120
PER	355	150	110	18	2	0	0	0	0	0	0	0	0	280
	SUM	1882 4393	1576 3678	490 1136	102 230	8 17	0 0	0 0	0 0	0 0	0 0	0 0	0 0	

Total No. Observations = 4264
Frequency Calm = 206 Per cent Calm = 4.83
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution - Speed vs Direction
December 1964-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	50	34	11	0	0	0	0	0	0	0	0	0	95
PER	5	116	77	25	2	0	0	0	0	0	0	0	0	220
FCY	6TO	40	29	6	1	0	0	0	0	0	0	0	0	76
PER	15	93	67	13	2	0	0	0	0	0	0	0	0	175
FCY	16TO	30	24	2	0	0	0	0	0	0	0	0	0	56
PER	25	69	55	4	0	0	0	0	0	0	0	0	0	129
FCY	26TO	33	10	1	0	0	0	0	0	0	0	0	0	44
PER	35	76	23	2	0	0	0	0	0	0	0	0	0	101
FCY	36TO	24	24	4	0	0	0	0	0	0	0	0	0	52
PER	45	55	55	9	0	0	0	0	0	0	0	0	0	119
FCY	46TO	23	13	1	0	0	0	0	0	0	0	0	0	37
PER	55	53	30	2	0	0	0	0	0	0	0	0	0	85
FCY	56TO	18	24	0	0	0	0	0	0	0	0	0	0	42
PER	65	41	55	0	0	0	0	0	0	0	0	0	0	96
FCY	66TO	28	23	4	0	0	0	0	0	0	0	0	0	55
PER	75	65	53	9	0	0	0	0	0	0	0	0	0	127
FCY	76TO	41	12	1	0	0	0	0	0	0	0	0	0	54
PER	85	95	27	2	0	0	0	0	0	0	0	0	0	124
FCY	86TO	25	17	3	0	0	0	0	0	0	0	0	0	45
PER	95	58	39	6	0	0	0	0	0	0	0	0	0	103
FCY	96TO	26	14	2	0	0	0	0	0	0	0	0	0	42
PER	105	60	32	4	0	0	0	0	0	0	0	0	0	96
FCY	106TO	23	2	0	0	0	0	0	0	0	0	0	0	25
PER	115	53	4	0	0	0	0	0	0	0	0	0	0	57
FCY	116TO	19	0	0	0	0	0	0	0	0	0	0	0	19
PER	125	44	0	0	0	0	0	0	0	0	0	0	0	44
FCY	126TO	29	2	0	0	0	0	0	0	0	0	0	0	31
PER	135	67	4	0	0	0	0	0	0	0	0	0	0	71
FCY	136TO	26	7	0	0	0	0	0	0	0	0	0	0	33
PER	145	60	16	0	0	0	0	0	0	0	0	0	0	76
FCY	146TO	31	34	1	0	0	0	0	0	0	0	0	0	66
PER	155	72	79	2	0	0	0	0	0	0	0	0	0	153
FCY	156TO	38	29	3	0	0	0	0	0	0	0	0	0	70
PER	165	88	67	6	0	0	0	0	0	0	0	0	0	161
FCY	166TO	45	22	7	0	0	0	0	0	0	0	0	0	74
PER	175	104	51	16	0	0	0	0	0	0	0	0	0	171
FCY	176TO	55	54	15	0	0	0	0	0	0	0	0	0	124
PER	185	128	125	34	0	0	0	0	0	0	0	0	0	287
FCY	186TO	106	103	13	6	0	0	0	0	0	0	0	0	228
PER	195	246	239	33	13	0	0	0	0	0	0	0	0	528
FCY	196TO	100	113	11	3	1	0	0	0	0	0	0	0	228
PER	205	232	263	25	6	2	0	0	0	0	0	0	0	528
FCY	206TO	88	96	11	0	0	0	0	0	0	0	0	0	195
PER	215	204	223	25	0	0	0	0	0	0	0	0	0	452
FCY	216TO	48	59	2	0	0	0	0	0	0	0	0	0	109
PER	225	111	137	4	0	0	0	0	0	0	0	0	0	252
FCY	226TO	57	18	2	0	0	0	0	0	0	0	0	0	77
PER	235	132	41	4	0	0	0	0	0	0	0	0	0	177
FCY	236TO	43	36	6	0	0	0	0	0	0	0	0	0	85
PER	245	100	83	13	0	0	0	0	0	0	0	0	0	196
FCY	246TO	45	30	5	0	0	0	0	0	0	0	0	0	80
PER	255	104	69	11	0	0	0	0	0	0	0	0	0	184
FCY	256TO	44	40	7	0	0	0	0	0	0	0	0	0	91
PER	265	102	93	16	0	0	0	0	0	0	0	0	0	211
FCY	266TO	62	28	16	0	0	0	0	0	0	0	0	0	106
PER	275	144	65	37	0	0	0	0	0	0	0	0	0	246
FCY	276TO	79	49	12	0	0	0	0	0	0	0	0	0	140
PER	285	183	114	27	0	0	0	0	0	0	0	0	0	324
FCY	286TO	98	84	24	5	0	0	0	0	0	0	0	0	211
PER	295	228	195	55	11	0	0	0	0	0	0	0	0	489
FCY	296TO	103	108	40	9	3	0	0	0	0	0	0	0	262
PER	305	239	251	93	18	6	0	0	0	0	0	0	0	607
FCY	306TO	93	110	52	17	8	0	0	0	0	0	0	0	280
PER	315	216	256	121	39	18	0	0	0	0	0	0	0	650
FCY	316TO	96	102	56	9	3	0	0	0	0	0	0	0	266
PER	325	223	237	130	20	6	0	0	0	0	0	0	0	616
FCY	326TO	120	104	40	8	0	0	0	0	0	0	0	0	272
PER	335	279	242	93	18	0	0	0	0	0	0	0	0	632
FCY	336TO	79	85	44	19	1	0	0	0	0	0	0	0	228
PER	345	183	197	102	44	2	0	0	0	0	0	0	0	528
FCY	346TO	53	68	24	7	0	0	0	0	0	0	0	0	152
PER	355	123	158	55	16	0	0	0	0	0	0	0	0	352
	SUM	1918	1607	426	83	16	0	0	0	0	0	0	0	
		4446	3724	975	187	34	0	0	0	0	0	0	0	

Total No. Observations = 4294
Frequency Calm = 244 Per cent Calm = 5.68
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations per hour, 48 per day

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
January 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	5	49	0	0	0	0	0	0	0	0	0	0	0	49
FCY	6TO	2	0	0	0	0	0	0	0	0	0	0	0	2
PER	15	24	0	0	0	0	0	0	0	0	0	0	0	24
FCY	16TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	25	49	0	0	0	0	0	0	0	0	0	0	0	49
FCY	26TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	35	37	0	0	0	0	0	0	0	0	0	0	0	37
FCY	36TO	5	0	0	0	0	0	0	0	0	0	0	0	5
PER	45	62	0	0	0	0	0	0	0	0	0	0	0	62
FCY	46TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	55	12	0	0	0	0	0	0	0	0	0	0	0	12
FCY	56TO	9	1	0	0	0	0	0	0	0	0	0	0	10
PER	65	111	12	0	0	0	0	0	0	0	0	0	0	123
FCY	66TO	6	2	0	0	0	0	0	0	0	0	0	0	8
PER	75	74	24	0	0	0	0	0	0	0	0	0	0	98
FCY	76TO	8	2	0	0	0	0	0	0	0	0	0	0	10
PER	85	99	24	0	0	0	0	0	0	0	0	0	0	123
FCY	86TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	95	49	0	0	0	0	0	0	0	0	0	0	0	49
FCY	96TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	105	37	0	0	0	0	0	0	0	0	0	0	0	37
FCY	106TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	115	12	0	0	0	0	0	0	0	0	0	0	0	12
FCY	116TO	5	0	0	0	0	0	0	0	0	0	0	0	5
PER	125	62	0	0	0	0	0	0	0	0	0	0	0	62
FCY	126TO	10	0	0	0	0	0	0	0	0	0	0	0	10
PER	135	124	0	0	0	0	0	0	0	0	0	0	0	124
FCY	136TO	14	0	0	0	0	0	0	0	0	0	0	0	14
PER	145	173	0	0	0	0	0	0	0	0	0	0	0	173
FCY	146TO	15	4	0	0	0	0	0	0	0	0	0	0	19
PER	155	186	49	0	0	0	0	0	0	0	0	0	0	235
FCY	156TO	15	2	0	0	0	0	0	0	0	0	0	0	17
PER	165	186	24	0	0	0	0	0	0	0	0	0	0	210
FCY	166TO	13	3	0	0	0	0	0	0	0	0	0	0	16
PER	175	161	37	0	0	0	0	0	0	0	0	0	0	198
FCY	176TO	21	3	0	0	0	0	0	0	0	0	0	0	24
PER	185	260	37	0	0	0	0	0	0	0	0	0	0	297
FCY	186TO	20	23	2	0	0	0	0	0	0	0	0	0	45
PER	195	248	285	24	0	0	0	0	0	0	0	0	0	557
FCY	196TO	10	26	3	0	0	0	0	0	0	0	0	0	39
PER	205	124	322	37	0	0	0	0	0	0	0	0	0	483
FCY	206TO	17	20	4	0	0	0	0	0	0	0	0	0	41
PER	215	211	248	49	0	0	0	0	0	0	0	0	0	508
FCY	216TO	24	8	0	0	0	0	0	0	0	0	0	0	32
PER	225	298	99	0	0	0	0	0	0	0	0	0	0	397
FCY	226TO	29	14	0	0	0	0	0	0	0	0	0	0	43
PER	235	360	173	0	0	0	0	0	0	0	0	0	0	533
FCY	236TO	24	6	1	0	0	0	0	0	0	0	0	0	31
PER	245	298	74	12	0	0	0	0	0	0	0	0	0	384
FCY	246TO	30	6	0	0	0	0	0	0	0	0	0	0	36
PER	255	372	74	0	0	0	0	0	0	0	0	0	0	446
FCY	256TO	26	2	0	0	0	0	0	0	0	0	0	0	28
PER	265	322	24	0	0	0	0	0	0	0	0	0	0	346
FCY	266TO	18	1	1	0	0	0	0	0	0	0	0	0	20
PER	275	223	12	12	0	0	0	0	0	0	0	0	0	247
FCY	276TO	16	1	0	0	0	0	0	0	0	0	0	0	17
PER	285	198	12	0	0	0	0	0	0	0	0	0	0	210
FCY	286TO	25	1	0	0	0	0	0	0	0	0	0	0	26
PER	295	310	12	0	0	0	0	0	0	0	0	0	0	322
FCY	296TO	28	1	0	0	0	0	0	0	0	0	0	0	29
PER	305	347	12	0	0	0	0	0	0	0	0	0	0	359
FCY	306TO	38	2	0	0	0	0	0	0	0	0	0	0	40
PER	315	472	24	0	0	0	0	0	0	0	0	0	0	496
FCY	316TO	35	8	0	0	0	0	0	0	0	0	0	0	43
PER	325	434	99	0	0	0	0	0	0	0	0	0	0	533
FCY	326TO	13	7	0	0	0	0	0	0	0	0	0	0	20
PER	335	161	86	0	0	0	0	0	0	0	0	0	0	247
FCY	336TO	9	4	0	0	0	0	0	0	0	0	0	0	13
PER	345	111	49	0	0	0	0	0	0	0	0	0	0	160
FCY	346TO	8	2	0	0	0	0	0	0	0	0	0	0	10
PER	355	99	24	0	0	0	0	0	0	0	0	0	0	123
	SUM	513	149	11	0	0	0	0	0	0	0	0	0	
		6355	1836	134	0	0	0	0	0	0	0	0	0	

Total No. Observations = 805
Frequency Calm = 132 Per cent Calm = 16.39
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
February 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

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          DIR     1-    6-   11-   16-   21-   26-   31-   36-   41-   46-   51-  OVER   SUM
          DEG      5    10    15    20    25    30    35    40    45    50    55    55
FCY     356TO      1     1     0     0     0     0     0     0     0     0     0     0
PER         5     18    18     0     0     0     0     0     0     0     0     0     0     2
FCY       6TO      0     0     0     0     0     0     0     0     0     0     0     0    36
PER        15      0     0     0     0     0     0     0     0     0     0     0     0     0
FCY      16TO      1     0     0     0     0     0     0     0     0     0     0     0     0
PER        25     18     0     0     0     0     0     0     0     0     0     0     0     1
FCY      26TO      2     0     0     0     0     0     0     0     0     0     0     0    18
PER        35     37     0     0     0     0     0     0     0     0     0     0     0     2
FCY      36TO      4     0     0     0     0     0     0     0     0     0     0     0    37
PER        45     74     0     0     0     0     0     0     0     0     0     0     0     4
FCY      46TO      5     1     0     0     0     0     0     0     0     0     0     0    74
PER        55     93    18     0     0     0     0     0     0     0     0     0     0     6
FCY      56TO      3     0     0     0     0     0     0     0     0     0     0     0   111
PER        65     55     0     0     0     0     0     0     0     0     0     0     0     3
FCY      66TO      9     2     0     0     0     0     0     0     0     0     0     0    55
PER        75    167    37     0     0     0     0     0     0     0     0     0     0    11
FCY      76TO     12     2     0     0     0     0     0     0     0     0     0     0   204
PER        85    223    37     0     0     0     0     0     0     0     0     0     0    14
FCY      86TO     22     4     1     0     0     0     0     0     0     0     0     0   260
PER        95    410    74    18     0     0     0     0     0     0     0     0     0    27
FCY      96TO     18     5     0     0     0     0     0     0     0     0     0     0   502
PER       105    335    93     0     0     0     0     0     0     0     0     0     0    23
FCY     106TO      7     0     0     0     0     0     0     0     0     0     0     0   428
PER       115    130     0     0     0     0     0     0     0     0     0     0     0     7
FCY     116TO      1     0     0     0     0     0     0     0     0     0     0     0   130
PER       125     18     0     0     0     0     0     0     0     0     0     0     0     1
FCY     126TO      4     0     0     0     0     0     0     0     0     0     0     0    18
PER       135     74     0     0     0     0     0     0     0     0     0     0     0     4
FCY     136TO     11     3     0     0     0     0     0     0     0     0     0     0    74
PER       145    205    55     0     0     0     0     0     0     0     0     0     0    14
FCY     146TO      8     2     0     0     0     0     0     0     0     0     0     0   260
PER       155    149    37     0     0     0     0     0     0     0     0     0     0    10
FCY     156TO      7     2     0     0     0     0     0     0     0     0     0     0   186
PER       165    130    37     0     0     0     0     0     0     0     0     0     0     9
FCY     166TO      7     1     0     0     0     0     0     0     0     0     0     0   167
PER       175    130    18     0     0     0     0     0     0     0     0     0     0     8
FCY     176TO      9     3     0     0     0     0     0     0     0     0     0     0   148
PER       185    167    55     0     0     0     0     0     0     0     0     0     0    12
FCY     186TO     14    10    11     0     0     0     0     0     0     0     0     0   222
PER       195    261   186   205     0     0     0     0     0     0     0     0     0    35
FCY     196TO     13     8     4     0     0     0     0     0     0     0     0     0   652
PER       205    242   149    74     0     0     0     0     0     0     0     0     0    25
FCY     206TO      6     3     0     0     0     0     0     0     0     0     0     0   465
PER       215    111    55     0     0     0     0     0     0     0     0     0     0     9
FCY     216TO      9     2     9     0     0     0     0     0     0     0     0     0   166
PER       225    167    37   167     0     0     0     0     0     0     0     0     0    20
FCY     226TO     18     2     2     0     0     0     0     0     0     0     0     0   371
PER       235    335    37    37     0     0     0     0     0     0     0     0     0    22
FCY     236TO     13     2     0     0     0     0     0     0     0     0     0     0   409
PER       245    242    37     0     0     0     0     0     0     0     0     0     0    15
FCY     246TO     14     0     0     0     0     0     0     0     0     0     0     0   279
PER       255    261     0     0     0     0     0     0     0     0     0     0     0    14
FCY     256TO     12     0     0     0     0     0     0     0     0     0     0     0   261
PER       265    223     0     0     0     0     0     0     0     0     0     0     0    12
FCY     266TO     18     0     0     0     0     0     0     0     0     0     0     0   223
PER       275    335     0     0     0     0     0     0     0     0     0     0     0    18
FCY     276TO      8     0     0     0     0     0     0     0     0     0     0     0   335
PER       285    149     0     0     0     0     0     0     0     0     0     0     0     8
FCY     286TO     16     0     0     0     0     0     0     0     0     0     0     0   149
PER       295    298     0     0     0     0     0     0     0     0     0     0     0    16
FCY     296TO     16     2     0     0     0     0     0     0     0     0     0     0   298
PER       305    298    37     0     0     0     0     0     0     0     0     0     0    18
FCY     306TO     13     2     0     0     0     0     0     0     0     0     0     0   335
PER       315    242    37     0     0     0     0     0     0     0     0     0     0    15
FCY     316TO     19    11     0     0     0     0     0     0     0     0     0     0   279
PER       325    354   205     0     0     0     0     0     0     0     0     0     0    30
FCY     326TO     21    13     0     0     0     0     0     0     0     0     0     0   559
PER       335    391   242     0     0     0     0     0     0     0     0     0     0    34
FCY     336TO      7     3     0     0     0     0     0     0     0     0     0     0   633
PER       345    130    55     0     0     0     0     0     0     0     0     0     0    10
FCY     346TO      3     0     1     0     0     0     0     0     0     0     0     0   185
PER       355     55     0    18     0     0     0     0     0     0     0     0     0     4
                                                                                      73
          SUM    351    84    28     0     0     0     0     0     0     0     0     0
                6527  1956   519     0     0     0     0     0     0     0     0     0
```

Total No. Observations = 536
Frequency Calm = 73 Per cent Calm = 13.61
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
March 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	8	7	0	0	0	0	0	0	0	0	0	0	15
PER	5	120	105	0	0	0	0	0	0	0	0	0	0	225
FCY	6TO	3	4	0	0	0	0	0	0	0	0	0	0	7
PER	15	45	60	0	0	0	0	0	0	0	0	0	0	105
FCY	16TO	9	0	0	0	0	0	0	0	0	0	0	0	9
PER	25	135	0	0	0	0	0	0	0	0	0	0	0	135
FCY	26TO	10	0	0	0	0	0	0	0	0	0	0	0	10
PER	35	151	0	0	0	0	0	0	0	0	0	0	0	151
FCY	36TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	45	45	0	0	0	0	0	0	0	0	0	0	0	45
FCY	46TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	55	45	0	0	0	0	0	0	0	0	0	0	0	45
FCY	56TO	6	1	0	0	0	0	0	0	0	0	0	0	7
PER	65	90	15	0	0	0	0	0	0	0	0	0	0	105
FCY	66TO	11	0	0	0	0	0	0	0	0	0	0	0	11
PER	75	166	0	0	0	0	0	0	0	0	0	0	0	166
FCY	76TO	13	0	0	0	0	0	0	0	0	0	0	0	13
PER	85	196	0	0	0	0	0	0	0	0	0	0	0	196
FCY	86TO	13	3	1	0	0	0	0	0	0	0	0	0	17
PER	95	196	45	15	0	0	0	0	0	0	0	0	0	256
FCY	96TO	10	2	0	0	0	0	0	0	0	0	0	0	12
PER	105	151	30	0	0	0	0	0	0	0	0	0	0	181
FCY	106TO	13	1	0	0	0	0	0	0	0	0	0	0	14
PER	115	196	15	0	0	0	0	0	0	0	0	0	0	211
FCY	116TO	6	0	0	0	0	0	0	0	0	0	0	0	6
PER	125	90	0	0	0	0	0	0	0	0	0	0	0	90
FCY	126TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	135	60	0	0	0	0	0	0	0	0	0	0	0	60
FCY	136TO	7	1	0	0	0	0	0	0	0	0	0	0	8
PER	145	105	15	0	0	0	0	0	0	0	0	0	0	120
FCY	146TO	8	3	0	0	0	0	0	0	0	0	0	0	11
PER	155	120	45	0	0	0	0	0	0	0	0	0	0	165
FCY	156TO	5	1	0	0	0	0	0	0	0	0	0	0	6
PER	165	75	15	0	0	0	0	0	0	0	0	0	0	90
FCY	166TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	175	60	0	0	0	0	0	0	0	0	0	0	0	60
FCY	176TO	15	1	1	0	0	0	0	0	0	0	0	0	17
PER	185	226	15	15	0	0	0	0	0	0	0	0	0	256
FCY	186TO	22	9	5	0	0	0	0	0	0	0	0	0	36
PER	195	332	135	75	0	0	0	0	0	0	0	0	0	542
FCY	196TO	22	20	1	0	0	0	0	0	0	0	0	0	43
PER	205	332	302	15	0	0	0	0	0	0	0	0	0	649
FCY	206TO	23	15	2	0	0	0	0	0	0	0	0	0	40
PER	215	347	226	30	0	0	0	0	0	0	0	0	0	603
FCY	216TO	10	3	2	0	0	0	0	0	0	0	0	0	15
PER	225	151	45	30	0	0	0	0	0	0	0	0	0	226
FCY	226TO	8	1	0	0	0	0	0	0	0	0	0	0	9
PER	235	120	15	0	0	0	0	0	0	0	0	0	0	135
FCY	236TO	12	2	0	0	0	0	0	0	0	0	0	0	14
PER	245	181	30	0	0	0	0	0	0	0	0	0	0	211
FCY	246TO	13	3	0	0	0	0	0	0	0	0	0	0	16
PER	255	196	45	0	0	0	0	0	0	0	0	0	0	241
FCY	256TO	16	2	0	0	0	0	0	0	0	0	0	0	18
PER	265	241	30	0	0	0	0	0	0	0	0	0	0	271
FCY	266TO	18	0	0	0	0	0	0	0	0	0	0	0	18
PER	275	271	0	0	0	0	0	0	0	0	0	0	0	271
FCY	276TO	17	1	0	0	0	0	0	0	0	0	0	0	18
PER	285	256	15	0	0	0	0	0	0	0	0	0	0	271
FCY	286TO	25	4	0	0	0	0	0	0	0	0	0	0	29
PER	295	377	60	0	0	0	0	0	0	0	0	0	0	437
FCY	296TO	26	3	1	0	0	0	0	0	0	0	0	0	30
PER	305	392	45	15	0	0	0	0	0	0	0	0	0	452
FCY	306TO	26	5	1	0	0	0	0	0	0	0	0	0	32
PER	315	392	75	15	0	0	0	0	0	0	0	0	0	482
FCY	316TO	20	10	0	0	0	0	0	0	0	0	0	0	30
PER	325	302	151	0	0	0	0	0	0	0	0	0	0	453
FCY	326TO	23	12	0	0	0	0	0	0	0	0	0	0	35
PER	335	347	181	0	0	0	0	0	0	0	0	0	0	528
FCY	336TO	10	0	0	0	0	0	0	0	0	0	0	0	10
PER	345	151	0	0	0	0	0	0	0	0	0	0	0	151
FCY	346TO	13	4	0	0	0	0	0	0	0	0	0	0	17
PER	355	196	60	0	0	0	0	0	0	0	0	0	0	256
	SUM	455	118	14	0	0	0	0	0	0	0	0	0	
		6856	1775	210	0	0	0	0	0	0	0	0	0	

Total No. Observations = 662
Frequency Calm = 75 Per cent Calm = 11.32
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction During Periods of Temperature Inversion April 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	10	2	0	0	0	0	0	0	0	0	0	0	12
PER	5	180	36	0	0	0	0	0	0	0	0	0	0	216
FCY	6TO	3	1	0	0	0	0	0	0	0	0	0	0	4
PER	15	54	18	0	0	0	0	0	0	0	0	0	0	72
FCY	16TO	6	1	0	0	0	0	0	0	0	0	0	0	7
PER	25	108	18	0	0	0	0	0	0	0	0	0	0	126
FCY	26TO	6	6	0	0	0	0	0	0	0	0	0	0	12
PER	35	108	108	0	0	0	0	0	0	0	0	0	0	216
FCY	36TO	5	6	0	0	0	0	0	0	0	0	0	0	11
PER	45	90	108	0	0	0	0	0	0	0	0	0	0	198
FCY	46TO	5	3	0	0	0	0	0	0	0	0	0	0	8
PER	55	90	54	0	0	0	0	0	0	0	0	0	0	144
FCY	56TO	10	0	0	0	0	0	0	0	0	0	0	0	10
PER	65	180	0	0	0	0	0	0	0	0	0	0	0	180
FCY	66TO	7	3	0	0	0	0	0	0	0	0	0	0	10
PER	75	126	54	0	0	0	0	0	0	0	0	0	0	180
FCY	76TO	5	1	0	0	0	0	0	0	0	0	0	0	6
PER	85	90	18	0	0	0	0	0	0	0	0	0	0	108
FCY	86TO	2	0	0	0	0	0	0	0	0	0	0	0	2
PER	95	36	0	0	0	0	0	0	0	0	0	0	0	36
FCY	96TO	2	0	0	0	0	0	0	0	0	0	0	0	2
PER	105	36	0	0	0	0	0	0	0	0	0	0	0	36
FCY	106TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	115	18	0	0	0	0	0	0	0	0	0	0	0	18
FCY	116TO	0	0	0	0	0	0	0	0	0	0	0	0	0
PER	125	0	0	0	0	0	0	0	0	0	0	0	0	0
FCY	126TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	135	18	0	0	0	0	0	0	0	0	0	0	0	18
FCY	136TO	6	1	0	0	0	0	0	0	0	0	0	0	7
PER	145	108	18	0	0	0	0	0	0	0	0	0	0	126
FCY	146TO	11	3	0	0	0	0	0	0	0	0	0	0	14
PER	155	198	54	0	0	0	0	0	0	0	0	0	0	252
FCY	156TO	12	2	0	0	0	0	0	0	0	0	0	0	14
PER	165	216	36	0	0	0	0	0	0	0	0	0	0	252
FCY	166TO	3	1	0	0	0	0	0	0	0	0	0	0	4
PER	175	54	18	0	0	0	0	0	0	0	0	0	0	72
FCY	176TO	12	1	0	0	0	0	0	0	0	0	0	0	13
PER	185	216	18	0	0	0	0	0	0	0	0	0	0	234
FCY	186TO	8	1	0	0	0	0	0	0	0	0	0	0	9
PER	195	144	18	0	0	0	0	0	0	0	0	0	0	162
FCY	196TO	10	2	0	0	0	0	0	0	0	0	0	0	12
PER	205	180	36	0	0	0	0	0	0	0	0	0	0	216
FCY	206TO	7	2	0	0	0	0	0	0	0	0	0	0	9
PER	215	126	36	0	0	0	0	0	0	0	0	0	0	162
FCY	216TO	10	2	0	0	0	0	0	0	0	0	0	0	12
PER	225	180	36	0	0	0	0	0	0	0	0	0	0	216
FCY	226TO	8	2	0	0	0	0	0	0	0	0	0	0	10
PER	235	144	36	0	0	0	0	0	0	0	0	0	0	180
FCY	236TO	6	1	0	0	0	0	0	0	0	0	0	0	7
PER	245	108	18	0	0	0	0	0	0	0	0	0	0	126
FCY	246TO	8	4	0	0	0	0	0	0	0	0	0	0	12
PER	255	144	72	0	0	0	0	0	0	0	0	0	0	216
FCY	256TO	8	4	0	0	0	0	0	0	0	0	0	0	12
PER	265	144	72	0	0	0	0	0	0	0	0	0	0	216
FCY	266TO	33	0	0	0	0	0	0	0	0	0	0	0	33
PER	275	596	0	0	0	0	0	0	0	0	0	0	0	596
FCY	276TO	24	2	0	0	0	0	0	0	0	0	0	0	26
PER	285	433	36	0	0	0	0	0	0	0	0	0	0	469
FCY	286TO	17	1	0	0	0	0	0	0	0	0	0	0	18
PER	295	307	18	0	0	0	0	0	0	0	0	0	0	325
FCY	296TO	15	0	0	0	0	0	0	0	0	0	0	0	15
PER	305	271	0	0	0	0	0	0	0	0	0	0	0	271
FCY	306TO	19	6	0	0	0	0	0	0	0	0	0	0	25
PER	315	343	108	0	0	0	0	0	0	0	0	0	0	451
FCY	316TO	27	31	0	0	0	0	0	0	0	0	0	0	58
PER	325	488	560	0	0	0	0	0	0	0	0	0	0	1048
FCY	326TO	24	32	0	0	0	0	0	0	0	0	0	0	56
PER	335	433	578	0	0	0	0	0	0	0	0	0	0	1011
FCY	336TO	23	12	0	0	0	0	0	0	0	0	0	0	35
PER	345	415	216	0	0	0	0	0	0	0	0	0	0	631
FCY	346TO	12	6	0	0	0	0	0	0	0	0	0	0	18
PER	355	216	108	0	0	0	0	0	0	0	0	0	0	324
	SUM	366	139	0	0	0	0	0	0	0	0	0	0	
		6598	2506	0	0	0	0	0	0	0	0	0	0	

Total No. Observations = 553
Frequency Calm = 48 Per cent Calm = 8.67
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
May 1965-1967: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1- 5	6- 1C	11- 15	16- 2C	21- 25	26- 30	31- 35	36- 4C	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TC	15	6	0	C	0	C	C	C	0	0	0	0	21
PER	5	212	85	C	C	0	C	C	C	0	C	0	0	297
FCY	6TO	17	11	C	C	0	C	C	0	0	0	0	0	28
PER	15	241	156	C	C	0	C	0	C	0	0	0	0	397
FCY	16TO	13	2	C	C	0	C	C	C	0	0	0	0	15
PER	25	184	28	C	0	0	C	0	0	0	0	0	0	212
FCY	26TC	6	3	C	C	C	C	0	0	0	0	0	0	9
PER	35	85	42	C	C	0	0	0	0	0	0	C	0	127
FCY	36TC	5	1	C	C	0	0	0	0	0	C	C	C	6
PER	45	7C	14	C	C	0	0	C	0	0	C	0	0	84
FCY	46TC	3	0	C	C	0	0	0	0	0	0	0	0	3
PER	55	42	0	0	C	0	0	0	C	0	0	0	0	42
FCY	56TC	5	0	C	0	0	0	0	0	0	0	0	0	5
PER	65	70	0	C	C	0	0	C	0	0	0	0	0	70
FCY	66TC	4	0	C	0	0	C	0	C	0	0	0	0	4
PER	75	56	C	C	0	0	C	C	C	0	0	0	0	56
FCY	76TC	5	0	C	0	0	0	0	C	0	0	0	0	5
PER	85	7C	0	C	C	0	C	C	0	0	0	0	0	70
FCY	86TO	9	1	0	C	C	C	0	0	0	0	0	0	10
PER	95	127	14	C	C	0	C	0	0	0	0	0	0	141
FCY	96TC	6	0	C	C	0	C	C	0	0	0	0	0	6
PER	1C5	85	0	C	C	0	C	0	0	0	0	0	0	85
FCY	106TC	4	C	0	C	0	C	0	0	0	0	0	0	4
PER	115	56	0	C	C	0	0	0	0	0	0	0	0	56
FCY	116TC	4	C	0	C	0	0	C	0	0	0	0	0	4
PER	125	56	0	0	C	0	0	0	0	0	0	0	0	56
FCY	126TC	5	0	C	C	0	C	0	0	0	0	0	0	5
PER	135	7C	0	C	C	0	0	0	0	0	0	0	0	70
FCY	136TC	3	5	C	C	0	C	0	0	0	0	0	0	8
PER	145	42	7C	C	0	0	0	C	0	0	0	0	C	112
FCY	146TO	3	1	0	C	0	0	0	0	0	0	0	0	4
PER	155	42	14	0	0	0	0	C	0	0	0	0	0	56
FCY	156TC	6	C	C	0	0	C	0	0	0	0	0	0	6
PER	165	85	0	C	C	0	0	C	0	0	0	0	0	85
FCY	166TC	6	1	C	C	0	0	0	0	0	0	0	0	7
PER	175	85	14	C	0	0	C	C	0	0	0	0	0	99
FCY	176TC	11	0	C	0	0	0	0	0	0	C	0	0	11
PER	185	156	0	C	C	0	0	C	0	0	0	0	0	156
FCY	186TO	20	6	0	C	0	0	0	C	0	0	0	0	26
PER	195	283	85	C	C	0	0	0	0	0	0	0	0	368
FCY	196TC	16	8	C	C	0	0	0	0	0	0	0	0	24
PER	205	226	113	C	C	0	0	0	0	0	0	0	0	339
FCY	206TC	8	9	C	C	0	0	C	0	0	0	0	0	17
PER	215	113	127	C	C	0	0	0	0	0	0	0	0	240
FCY	216TC	17	2	0	C	0	0	0	0	0	0	0	0	19
PER	225	241	28	0	0	0	0	0	0	0	0	0	0	269
FCY	226TC	17	7	C	0	0	0	0	0	0	0	0	0	24
PER	235	241	99	0	0	0	0	0	0	0	0	0	0	340
FCY	236TC	15	8	0	0	0	0	0	0	0	0	0	0	23
PER	245	212	113	0	0	0	0	0	0	0	0	0	0	325
FCY	246TO	18	3	0	C	0	0	0	0	0	0	0	0	21
PER	255	255	42	0	C	0	0	C	0	0	0	0	0	297
FCY	256TC	21	4	C	C	0	C	C	C	0	C	0	0	25
PER	265	297	56	0	C	0	0	0	0	0	0	0	0	353
FCY	266TC	12	2	C	C	0	0	0	0	0	0	0	0	14
PER	275	170	28	C	0	0	0	0	0	0	0	0	0	198
FCY	276TC	20	0	C	C	0	0	C	C	0	0	0	0	20
PER	285	283	0	C	C	0	0	0	0	0	0	0	0	283
FCY	286TC	27	0	C	C	0	C	C	0	0	0	0	0	27
PER	295	382	C	0	C	0	0	0	0	0	0	0	0	382
FCY	296TC	25	3	C	C	0	0	C	0	0	0	0	0	28
PER	305	354	42	C	C	0	0	0	0	0	0	0	0	396
FCY	306TO	22	11	0	C	0	0	0	0	0	0	0	0	33
PER	315	312	156	C	0	0	0	0	0	0	0	0	0	468
FCY	316TC	16	19	C	C	0	0	C	0	0	0	0	0	35
PER	325	226	269	C	C	0	0	0	0	0	0	0	0	495
FCY	326TC	28	12	C	0	0	0	C	0	0	0	0	0	40
PER	335	397	17C	C	C	0	0	0	0	0	0	0	0	567
FCY	336TO	25	13	C	0	0	0	C	0	0	0	0	0	38
PER	345	354	184	C	C	0	0	C	0	0	0	0	0	538
FCY	346TC	18	5	C	0	0	0	0	0	0	0	0	0	23
PER	355	255	76	C	C	0	0	0	0	0	0	0	0	325
	SUM	455	143	C	C	0	0	0	0	0	0	0	0	
		6435	2C19	C	C	0	0	C	0	0	0	0	0	

Total No. Observations = 705
Frequency Calm = 107 Per cent Calm = 15.17
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
June 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1- 5	6- 10	11- 15	16- 20	21- 25	26- 30	31- 35	36- 40	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TO	6	12	0	0	0	0	0	0	0	0	0	0	18
PER	5	76	152	0	0	0	0	0	0	0	0	0	0	228
FCY	6TO	9	5	0	0	0	0	0	0	0	0	0	0	14
PER	15	114	63	0	0	0	0	0	0	0	0	0	0	177
FCY	16TO	10	1	0	0	0	0	0	0	0	0	0	0	11
PER	25	126	12	0	0	0	0	0	0	0	0	0	0	138
FCY	26TO	6	1	0	0	0	0	0	0	0	0	0	0	7
PER	35	76	12	0	0	0	0	0	0	0	0	0	0	88
FCY	36TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	45	38	0	0	0	0	0	0	0	0	0	0	0	38
FCY	46TO	1	1	0	0	0	0	0	0	0	0	0	0	2
PER	55	12	12	0	0	0	0	0	0	0	0	0	0	24
FCY	56TO	2	1	0	0	0	0	0	0	0	0	0	0	3
PER	65	25	12	0	0	0	0	0	0	0	0	0	0	37
FCY	66TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	75	12	0	0	0	0	0	0	0	0	0	0	0	12
FCY	76TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	85	38	0	0	0	0	0	0	0	0	0	0	0	38
FCY	86TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	95	38	0	0	0	0	0	0	0	0	0	0	0	38
FCY	96TO	2	0	0	0	0	0	0	0	0	0	0	0	2
PER	105	25	0	0	0	0	0	0	0	0	0	0	0	25
FCY	106TO	2	0	0	0	0	0	0	0	0	0	0	0	2
PER	115	25	0	0	0	0	0	0	0	0	0	0	0	25
FCY	116TO	0	0	0	0	0	0	0	0	0	0	0	0	0
PER	125	0	0	0	0	0	0	0	0	0	0	0	0	0
FCY	126TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	135	50	0	0	0	0	0	0	0	0	0	0	0	50
FCY	136TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	145	50	0	0	0	0	0	0	0	0	0	0	0	50
FCY	146TO	2	0	0	0	0	0	0	0	0	0	0	0	2
PER	155	25	0	0	0	0	0	0	0	0	0	0	0	25
FCY	156TO	8	0	0	0	0	0	0	0	0	0	0	0	8
PER	165	101	0	0	0	0	0	0	0	0	0	0	0	101
FCY	166TO	13	0	0	0	0	0	0	0	0	0	0	0	13
PER	175	164	0	0	0	0	0	0	0	0	0	0	0	164
FCY	176TO	17	0	0	0	0	0	0	0	0	0	0	0	17
PER	185	215	0	0	0	0	0	0	0	0	0	0	0	215
FCY	186TO	29	5	0	0	0	0	0	0	0	0	0	0	34
PER	195	367	63	0	0	0	0	0	0	0	0	0	0	430
FCY	196TO	41	10	0	0	0	0	0	0	0	0	0	0	51
PER	205	519	126	0	0	0	0	0	0	0	0	0	0	645
FCY	206TO	23	32	0	0	0	0	0	0	0	0	0	0	55
PER	215	291	405	0	0	0	0	0	0	0	0	0	0	696
FCY	216TO	27	18	0	0	0	0	0	0	0	0	0	0	45
PER	225	342	228	0	0	0	0	0	0	0	0	0	0	570
FCY	226TO	18	10	0	0	0	0	0	0	0	0	0	0	28
PER	235	228	126	0	0	0	0	0	0	0	0	0	0	354
FCY	236TO	19	13	0	0	0	0	0	0	0	0	0	0	32
PER	245	240	164	0	0	0	0	0	0	0	0	0	0	404
FCY	246TO	20	1	0	0	0	0	0	0	0	0	0	0	21
PER	255	253	12	0	0	0	0	0	0	0	0	0	0	265
FCY	256TO	26	5	0	0	0	0	0	0	0	0	0	0	31
PER	265	329	63	0	0	0	0	0	0	0	0	0	0	392
FCY	266TO	17	2	0	0	0	0	0	0	0	0	0	0	19
PER	275	215	25	0	0	0	0	0	0	0	0	0	0	240
FCY	276TO	30	0	0	0	0	0	0	0	0	0	0	0	30
PER	285	380	0	0	0	0	0	0	0	0	0	0	0	380
FCY	286TO	24	0	0	0	0	0	0	0	0	0	0	0	24
PER	295	304	0	0	0	0	0	0	0	0	0	0	0	304
FCY	296TO	25	2	0	0	0	0	0	0	0	0	0	0	27
PER	305	316	25	0	0	0	0	0	0	0	0	0	0	341
FCY	306TO	31	10	1	0	0	0	0	0	0	0	0	0	42
PER	315	392	126	12	0	0	0	0	0	0	0	0	0	530
FCY	316TO	48	30	0	0	0	0	0	0	0	0	0	0	78
PER	325	608	380	0	0	0	0	0	0	0	0	0	0	988
FCY	326TO	21	36	0	0	0	0	0	0	0	0	0	0	57
PER	335	266	456	0	0	0	0	0	0	0	0	0	0	722
FCY	336TO	14	16	0	0	0	0	0	0	0	0	0	0	30
PER	345	177	202	0	0	0	0	0	0	0	0	0	0	379
FCY	346TO	9	10	0	0	0	0	0	0	0	0	0	0	19
PER	355	114	126	0	0	0	0	0	0	0	0	0	0	240
SUM		518	221	1	0	0	0	0	0	0	0	0	0	
		6551	2790	12	0	0	0	0	0	0	0	0	0	

Total No. Observations = 789
Frequency Calm = 49 Per cent Calm = 6.21
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction During Periods of Temperature Inversion July 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR CEG	1- 5	6- 1C	11- 15	16- 2C	21- 25	26- 3C	31- 35	36- 4C	41- 45	46- 50	51- 55	OVER 55	SUM
FCY	356TC	31	1C	C	C	0	0	0	0	0	0	0	0	41
PER	5	339	1C9	C	C	0	0	C	0	0	0	C	0	448
FCY	6TC	35	12	C	C	0	0	0	C	0	0	0	0	47
PER	15	383	131	C	C	0	C	0	0	0	0	0	0	514
FCY	16TC	15	4	C	C	0	0	C	C	0	0	C	0	19
PER	25	164	43	C	C	0	0	C	0	0	0	0	0	207
FCY	26TC	15	4	C	C	0	C	C	0	0	0	0	0	19
PER	35	164	43	C	C	0	C	0	0	0	0	0	0	207
FCY	36TC	12	1	C	C	0	C	0	0	0	0	0	0	13
PER	45	131	1C	C	C	0	C	0	0	0	0	0	0	141
FCY	46TC	15	C	C	C	0	C	0	0	0	0	0	0	15
PER	55	164	C	C	C	0	0	0	0	0	0	0	0	164
FCY	56TC	8	1	C	C	0	0	C	0	0	0	0	0	9
PER	65	87	1C	C	0	0	0	0	0	0	0	0	0	97
FCY	66TC	9	C	C	C	0	C	0	C	0	0	0	0	9
PER	75	98	0	C	0	0	0	0	0	0	0	0	0	98
FCY	76TC	9	1	C	0	0	C	0	0	0	0	0	0	10
PER	85	98	10	C	0	0	C	C	C	0	0	0	0	108
FCY	86TC	2	0	C	C	0	0	C	0	0	0	C	0	2
PER	95	21	C	C	C	0	C	C	0	0	0	0	0	21
FCY	96TC	2	0	C	0	0	0	C	0	0	0	0	0	2
PER	105	21	C	C	C	0	0	0	0	0	0	0	0	21
FCY	1C6TC	1	0	C	C	0	0	0	C	0	0	0	0	1
PER	115	1C	C	C	C	0	0	C	0	0	0	0	0	10
FCY	116TC	3	0	C	C	0	0	C	0	0	0	0	0	3
PER	125	32	C	C	C	0	0	0	0	0	0	0	0	32
FCY	126TC	4	C	C	0	0	C	0	0	0	0	0	0	4
PER	135	43	C	C	0	0	0	0	0	0	0	0	0	43
FCY	136TC	9	0	C	C	C	0	C	0	0	0	0	0	9
PER	145	98	0	C	C	0	0	0	0	0	0	0	0	98
FCY	146TC	11	2	C	C	0	C	0	0	C	0	0	0	13
PER	155	12C	21	C	0	0	C	0	0	0	0	0	0	141
FCY	156TC	12	9	C	0	0	C	0	0	0	0	0	0	21
PER	165	131	58	C	C	0	C	0	0	0	0	0	0	229
FCY	166TC	16	3	C	0	0	C	0	C	0	0	C	0	19
PER	[illegible]	175	32	0	C	0	0	0	0	0	0	0	0	207
FCY	[illegible]	23	2	C	0	0	0	0	0	0	0	0	0	25
PER	[illegible]	251	21	C	C	0	C	0	C	0	0	0	0	272
FCY	186TC	32	11	C	C	0	0	0	0	0	0	0	0	43
PER	195	35C	12C	C	C	0	0	0	0	0	0	0	0	470
FCY	196TC	25	9	C	0	0	0	C	0	0	0	0	0	34
PER	205	273	58	C	C	0	0	C	0	0	0	0	0	371
FCY	2C6TC	13	4	C	C	0	C	C	0	0	0	0	0	17
PER	215	142	43	C	C	0	0	0	C	0	0	0	0	185
FCY	216TC	1C	5	C	C	0	0	0	0	0	0	0	0	15
PER	225	1C9	54	C	C	0	0	0	0	0	0	0	0	163
FCY	226TC	16	6	C	C	0	C	C	0	0	0	0	0	22
PER	235	175	65	C	C	0	C	0	0	0	0	0	0	240
FCY	236TC	10	11	C	0	0	0	0	0	0	0	0	0	21
PER	245	1C9	12C	C	0	0	0	0	0	0	0	0	0	229
FCY	246TC	21	2	C	0	0	0	0	0	0	0	0	0	23
PER	255	230	21	C	0	0	0	0	0	0	0	0	0	251
FCY	256TC	19	2	C	C	0	0	0	0	0	0	0	0	21
PER	265	208	21	C	0	0	0	C	0	0	0	0	0	229
FCY	266TC	24	C	C	0	0	0	0	C	0	0	0	0	24
PER	275	262	0	C	0	0	0	0	0	0	0	0	0	262
FCY	276TC	16	C	C	C	0	0	C	0	0	0	0	0	16
PER	285	175	C	C	C	0	0	0	0	0	0	0	0	175
FCY	286TC	12	0	C	C	0	0	0	0	0	0	0	0	12
PER	295	131	C	C	C	0	0	0	0	0	0	0	0	131
FCY	296TC	18	C	C	C	0	0	0	C	0	0	0	0	18
PER	3C5	197	C	C	C	0	0	0	0	0	0	0	0	197
FCY	3C6TC	27	C	C	C	0	0	0	C	0	0	0	C	27
PER	315	295	C	C	0	0	0	C	0	0	0	0	0	295
FCY	316TC	28	11	C	C	0	C	C	0	0	0	0	0	39
PER	325	3C6	12C	C	C	0	0	0	0	0	0	0	0	426
FCY	326TC	37	46	C	C	0	C	0	0	0	0	0	0	83
PER	335	4C5	5C3	C	C	0	C	C	0	0	0	0	0	908
FCY	336TC	45	12	C	0	0	C	0	0	0	0	0	0	57
PER	345	492	131	C	C	0	0	C	0	0	0	0	0	623
FCY	346TC	31	21	C	0	0	0	C	0	0	0	0	0	52
PER	355	339	23C	C	C	0	0	0	0	0	0	0	0	569
	SUM	816	189	C	C	0	C	0	0	0	0	0	0	
		6728	2C54	C	C	0	C	0	0	0	0	0	0	

Total No. Observations = 913
Frequency Calm = 108 Per cent Calm = 11.82
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction During Periods of Temperature Inversion August 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

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       DIR     1-    6-   11-   16-   21-   26-   31-   36-   41-   46-   51-  OVER   SUM
       DEG      5    10    15    20    25    30    35    40    45    50    55    55
FCY  356TO     14     2     0     0     0     0     0     0     0     0     0     0    16
PER      5    185    26     0     0     0     0     0     0     0     0     0     0   211
FCY    6TO      6     1     0     0     0     0     0     0     0     0     0     0     7
PER     15     79    13     0     0     0     0     0     0     0     0     0     0    92
FCY   16TO      9     0     0     0     0     0     0     0     0     0     0     0     9
PER     25    119     0     0     0     0     0     0     0     0     0     0     0   119
FCY   26TO      4     0     0     0     0     0     0     0     0     0     0     0     4
PER     35     52     0     0     0     0     0     0     0     0     0     0     0    52
FCY   36TO      2     0     0     0     0     0     0     0     0     0     0     0     2
PER     45     26     0     0     0     0     0     0     0     0     0     0     0    26
FCY   46TO      5     0     0     0     0     0     0     0     0     0     0     0     5
PER     55     66     0     0     0     0     0     0     0     0     0     0     0    66
FCY   56TO      5     1     0     0     0     0     0     0     0     0     0     0     6
PER     65     66    13     0     0     0     0     0     0     0     0     0     0    79
FCY   66TO      3     0     0     0     0     0     0     0     0     0     0     0     3
PER     75     39     0     0     0     0     0     0     0     0     0     0     0    39
FCY   76TO      9     0     0     0     0     0     0     0     0     0     0     0     9
PER     85    119     0     0     0     0     0     0     0     0     0     0     0   119
FCY   86TO      5     0     0     0     0     0     0     0     0     0     0     0     5
PER     95     66     0     0     0     0     0     0     0     0     0     0     0    66
FCY   96TO      2     0     0     0     0     0     0     0     0     0     0     0     2
PER    105     26     0     0     0     0     0     0     0     0     0     0     0    26
FCY  106TO      1     0     0     0     0     0     0     0     0     0     0     0     1
PER    115     13     0     0     0     0     0     0     0     0     0     0     0    13
FCY  116TO      2     0     0     0     0     0     0     0     0     0     0     0     2
PER    125     26     0     0     0     0     0     0     0     0     0     0     0    26
FCY  126TO      3     0     0     0     0     0     0     0     0     0     0     0     3
PER    135     39     0     0     0     0     0     0     0     0     0     0     0    39
FCY  136TO      7     0     0     0     0     0     0     0     0     0     0     0     7
PER    145     92     0     0     0     0     0     0     0     0     0     0     0    92
FCY  146TO     11     0     0     0     0     0     0     0     0     0     0     0    11
PER    155    145     0     0     0     0     0     0     0     0     0     0     0   145
FCY  156TO      4     0     0     0     0     0     0     0     0     0     0     0     4
PER    165     52     0     0     0     0     0     0     0     0     0     0     0    52
FCY  166TO      3     0     0     0     0     0     0     0     0     0     0     0     3
PER    175     39     0     0     0     0     0     0     0     0     0     0     0    39
FCY  176TO      8     1     0     0     0     0     0     0     0     0     0     0     9
PER    185    105    13     0     0     0     0     0     0     0     0     0     0   118
FCY  186TO     14     3     0     0     0     0     0     0     0     0     0     0    17
PER    195    185    39     0     0     0     0     0     0     0     0     0     0   224
FCY  196TO     22    12     0     0     0     0     0     0     0     0     0     0    34
PER    205    291   158     0     0     0     0     0     0     0     0     0     0   449
FCY  206TO     18     4     0     0     0     0     0     0     0     0     0     0    22
PER    215    238    52     0     0     0     0     0     0     0     0     0     0   290
FCY  216TO      6     2     0     0     0     0     0     0     0     0     0     0     8
PER    225     79    26     0     0     0     0     0     0     0     0     0     0   105
FCY  226TO      7     2     0     0     0     0     0     0     0     0     0     0     9
PER    235     92    26     0     0     0     0     0     0     0     0     0     0   118
FCY  236TO      8     5     0     0     0     0     0     0     0     0     0     0    13
PER    245    105    66     0     0     0     0     0     0     0     0     0     0   171
FCY  246TO     17     0     0     0     0     0     0     0     0     0     0     0    17
PER    255    225     0     0     0     0     0     0     0     0     0     0     0   225
FCY  256TO      9     4     0     0     0     0     0     0     0     0     0     0    13
PER    265    119    52     0     0     0     0     0     0     0     0     0     0   171
FCY  266TO     17     0     0     0     0     0     0     0     0     0     0     0    17
PER    275    225     0     0     0     0     0     0     0     0     0     0     0   225
FCY  276TO     35     2     0     0     0     0     0     0     0     0     0     0    37
PER    285    463    26     0     0     0     0     0     0     0     0     0     0   489
FCY  286TO     32     1     0     0     0     0     0     0     0     0     0     0    33
PER    295    423    13     0     0     0     0     0     0     0     0     0     0   436
FCY  296TO     38     0     0     0     0     0     0     0     0     0     0     0    38
PER    305    503     0     0     0     0     0     0     0     0     0     0     0   503
FCY  306TO     51     7     0     0     0     0     0     0     0     0     0     0    58
PER    315    675    92     0     0     0     0     0     0     0     0     0     0   767
FCY  316TO     61    21     0     0     0     0     0     0     0     0     0     0    82
PER    325    807   278     0     0     0     0     0     0     0     0     0     0  1085
FCY  326TO     48    29     0     0     0     0     0     0     0     0     0     0    77
PER    335    635   384     0     0     0     0     0     0     0     0     0     0  1019
FCY  336TO     28    16     0     0     0     0     0     0     0     0     0     0    44
PER    345    370   211     0     0     0     0     0     0     0     0     0     0   581
FCY  346TO     18    10     0     0     0     0     0     0     0     0     0     0    28
PER    355    238   132     0     0     0     0     0     0     0     0     0     0   370

       SUM    532   123     0     0     0     0     0     0     0     0     0     0
             7027  1620     0     0     0     0     0     0     0     0     0     0
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Total No. Observations = 755
Frequency Calm = 100 Per cent Calm = 13.24
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
September 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	20	2	0	0	0	0	0	0	0	0	0	0	22
PER	5	265	26	0	0	0	0	0	0	0	0	0	0	291
FCY	6TO	14	4	0	0	0	0	0	0	0	0	0	0	18
PER	15	186	53	0	0	0	0	0	0	0	0	0	0	239
FCY	16TO	12	2	0	0	0	0	0	0	0	0	0	0	14
PER	25	159	26	0	0	0	0	0	0	0	0	0	0	185
FCY	26TO	16	0	0	0	0	0	0	0	0	0	0	0	16
PER	35	212	0	0	0	0	0	0	0	0	0	0	0	212
FCY	36TO	9	1	0	0	0	0	0	0	0	0	0	0	10
PER	45	119	13	0	0	0	0	0	0	0	0	0	0	132
FCY	46TO	9	2	0	0	0	0	0	0	0	0	0	0	11
PER	55	119	26	0	0	0	0	0	0	0	0	0	0	145
FCY	56TO	11	6	0	0	0	0	0	0	0	0	0	0	17
PER	65	146	79	0	0	0	0	0	0	0	0	0	0	225
FCY	66TO	8	6	0	0	0	0	0	0	0	0	0	0	14
PER	75	106	79	0	0	0	0	0	0	0	0	0	0	185
FCY	76TO	9	3	0	0	0	0	0	0	0	0	0	0	12
PER	85	119	39	0	0	0	0	0	0	0	0	0	0	158
FCY	86TO	11	1	0	0	0	0	0	0	0	0	0	0	12
PER	95	146	13	0	0	0	0	0	0	0	0	0	0	159
FCY	96TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	105	39	0	0	0	0	0	0	0	0	0	0	0	39
FCY	106TO	8	0	0	0	0	0	0	0	0	0	0	0	8
PER	115	106	0	0	0	0	0	0	0	0	0	0	0	106
FCY	116TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	125	39	0	0	0	0	0	0	0	0	0	0	0	39
FCY	126TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	135	53	0	0	0	0	0	0	0	0	0	0	0	53
FCY	136TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	145	13	0	0	0	0	0	0	0	0	0	0	0	13
FCY	146TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	155	39	0	0	0	0	0	0	0	0	0	0	0	39
FCY	156TO	6	0	0	0	0	0	0	0	0	0	0	0	6
PER	165	79	0	0	0	0	0	0	0	0	0	0	0	79
FCY	166TO	7	0	0	0	0	0	0	0	0	0	0	0	7
PER	175 .	53	0	0	0	0	0	0	0	0	0	0	0	93
FCY	176TO	6	2	0	0	0	0	0	0	0	0	0	0	8
PER	185	79	26	0	0	0	0	0	0	0	0	0	0	105
FCY	186TO	14	1	0	0	0	0	0	0	0	0	0	0	15
PER	195	186	13	0	0	0	0	0	0	0	0	0	0	199
FCY	196TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	205	53	0	0	0	0	0	0	0	0	0	0	0	53
FCY	206TO	4	4	0	0	0	0	0	0	0	0	0	0	8
PER	215	53	53	0	0	0	0	0	0	0	0	0	0	106
FCY	216TO	4	6	0	0	0	0	0	0	0	0	0	0	10
PER	225	53	79	0	0	0	0	0	0	0	0	0	0	132
FCY	226TO	11	2	0	0	0	0	0	0	0	0	0	0	13
PER	235	146	26	0	0	0	0	0	0	0	0	0	0	172
FCY	236TO	11	1	0	0	0	0	0	0	0	0	0	0	12
PER	245	146	13	0	0	0	0	0	0	0	0	0	0	159
FCY	246TO	18	7	0	0	0	0	0	0	0	0	0	0	25
PER	255	239	53	0	0	0	0	0	0	0	0	0	0	332
FCY	256TO	14	2	0	0	0	0	0	0	0	0	0	0	16
PER	265	186	26	0	0	0	0	0	0	0	0	0	0	212
FCY	266TO	18	6	0	0	0	0	0	0	0	0	0	0	24
PER	275	239	79	0	0	0	0	0	0	0	0	0	0	318
FCY	276TO	26	1	0	0	0	0	0	0	0	0	0	0	27
PER	285	345	13	0	0	0	0	0	0	0	0	0	0	358
FCY	286TO	24	0	0	0	0	0	0	0	0	0	0	0	24
PER	295	319	0	0	0	0	0	0	0	0	0	0	0	319
FCY	296TO	39	0	0	0	0	0	0	0	0	0	0	0	39
PER	305	518	0	0	0	0	0	0	0	0	0	0	0	518
FCY	306TO	30	1	0	0	0	0	0	0	0	0	0	0	31
PER	315	398	13	0	0	0	0	0	0	0	0	0	0	411
FCY	316TO	43	34	0	0	0	0	0	0	0	0	0	0	77
PER	325	571	452	0	0	0	0	0	0	0	0	0	0	1023
FCY	326TO	59	58	0	0	0	0	0	0	0	0	0	0	117
PER	335	784	771	0	0	0	0	0	0	0	0	0	0	1555
FCY	336TO	26	12	0	0	0	0	0	0	0	0	0	0	38
PER	345	345	159	0	0	0	0	0	0	0	0	0	0	504
FCY	346TO	17	4	0	0	0	0	0	0	0	0	0	0	21
PER	355	226	53	0	0	0	0	0	0	0	0	0	0	279
	SUM	522 6924	168 2223	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	

Total No. Observations = 752
Frequency Calm = 62 Per cent Calm = 8.24
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
October 1965-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	12	2	0	0	0	0	0	0	0	0	0	0	14
PER	5	115	19	0	0	0	0	0	0	0	0	0	0	134
FCY	6TO	10	4	0	0	0	0	0	0	0	0	0	0	14
PER	15	96	38	0	0	0	0	0	0	0	0	0	0	134
FCY	16TO	5	0	0	0	0	0	0	0	0	0	0	0	5
PER	25	48	0	0	0	0	0	0	0	0	0	0	0	48
FCY	26TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	35	28	0	0	0	0	0	0	0	0	0	0	0	28
FCY	36TO	2	1	0	0	0	0	0	0	0	0	0	0	3
PER	45	19	9	0	0	0	0	0	0	0	0	0	0	28
FCY	46TO	3	0	0	0	0	0	0	0	0	0	0	0	3
PER	55	28	0	0	0	0	0	0	0	0	0	0	0	28
FCY	56TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	65	9	0	0	0	0	0	0	0	0	0	0	0	9
FCY	66TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	75	38	0	0	0	0	0	0	0	0	0	0	0	38
FCY	76TO	5	0	0	0	0	0	0	0	0	0	0	0	5
PER	85	48	0	0	0	0	0	0	0	0	0	0	0	48
FCY	86TO	1	0	0	0	0	0	0	0	0	0	0	0	1
PER	95	9	0	0	0	0	0	0	0	0	0	0	0	9
FCY	96TO	7	0	0	0	0	0	0	0	0	0	0	0	7
PER	105	67	0	0	0	0	0	0	0	0	0	0	0	67
FCY	106TO	5	0	0	0	0	0	0	0	0	0	0	0	5
PER	115	48	0	0	0	0	0	0	0	0	0	0	0	48
FCY	116TO	6	0	0	0	0	0	0	0	0	0	0	0	6
PER	125	57	0	0	0	0	0	0	0	0	0	0	0	57
FCY	126TO	8	1	0	0	0	0	0	0	0	0	0	0	9
PER	135	77	9	0	0	0	0	0	0	0	0	0	0	86
FCY	136TO	6	1	0	0	0	0	0	0	0	0	0	0	7
PER	145	57	9	0	0	0	0	0	0	0	0	0	0	66
FCY	146TO	6	2	0	0	0	0	0	0	0	0	0	0	8
PER	155	57	19	0	0	0	0	0	0	0	0	0	0	76
FCY	156TO	8	0	0	0	0	0	0	0	0	0	0	0	8
PER	165	77	0	0	0	0	0	0	0	0	0	0	0	77
FCY	166TO	12	0	0	0	0	0	0	0	0	0	0	0	12
PER	175	115	0	0	0	0	0	0	0	0	0	0	0	115
FCY	176TO	18	1	0	0	0	0	0	0	0	0	0	0	19
PER	185	173	9	0	0	0	0	0	0	0	0	0	0	182
FCY	186TO	32	10	0	0	0	0	0	0	0	0	0	0	42
PER	195	309	96	0	0	0	0	0	0	0	0	0	0	405
FCY	196TO	34	16	0	0	0	0	0	0	0	0	0	0	50
PER	205	328	154	0	0	0	0	0	0	0	0	0	0	482
FCY	206TO	21	18	0	0	0	0	0	0	0	0	0	0	39
PER	215	202	173	0	0	0	0	0	0	0	0	0	0	375
FCY	216TO	25	17	0	0	0	0	0	0	0	0	0	0	42
PER	225	241	164	0	0	0	0	0	0	0	0	0	0	405
FCY	226TO	33	11	0	0	0	0	0	0	0	0	0	0	44
PER	235	318	106	0	0	0	0	0	0	0	0	0	0	424
FCY	236TO	37	19	0	0	0	0	0	0	0	0	0	0	56
PER	245	357	183	0	0	0	0	0	0	0	0	0	0	540
FCY	246TO	43	11	0	0	0	0	0	0	0	0	0	0	54
PER	255	415	106	0	0	0	0	0	0	0	0	0	0	521
FCY	256TO	37	8	0	0	0	0	0	0	0	0	0	0	45
PER	265	357	77	0	0	0	0	0	0	0	0	0	0	434
FCY	266TO	31	0	0	0	0	0	0	0	0	0	0	0	31
PER	275	299	0	0	0	0	0	0	0	0	0	0	0	299
FCY	276TO	34	0	0	0	0	0	0	0	0	0	0	0	34
PER	285	328	0	0	0	0	0	0	0	0	0	0	0	328
FCY	286TO	34	0	0	0	0	0	0	0	0	0	0	0	34
PER	295	328	0	0	0	0	0	0	0	0	0	0	0	328
FCY	296TO	42	3	0	0	0	0	0	0	0	0	0	0	45
PER	305	405	28	0	0	0	0	0	0	0	0	0	0	433
FCY	306TO	53	10	0	0	0	0	0	0	0	0	0	0	63
PER	315	512	96	0	0	0	0	0	0	0	0	0	0	608
FCY	316TO	53	30	0	0	0	0	0	0	0	0	0	0	83
PER	325	512	289	0	0	0	0	0	0	0	0	0	0	801
FCY	326TO	46	20	0	0	0	0	0	0	0	0	0	0	66
PER	335	444	193	0	0	0	0	0	0	0	0	0	0	637
FCY	336TO	26	14	0	0	0	0	0	0	0	0	0	0	40
PER	345	251	135	0	0	0	0	0	0	0	0	0	0	386
FCY	346TO	11	3	0	0	0	0	0	0	0	0	0	0	14
PER	355	106	28	0	0	0	0	0	0	0	0	0	0	134
	SUM	714	202	0	0	0	0	0	0	0	0	0	0	
		6878	1940	0	0	0	0	0	0	0	0	0	0	

Total No. Observations = 1035
Frequency Calm = 119 Per cent Calm = 11.49
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
November 1964-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

	DIR DEG	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	OVER 55	SUM
FCY	356TO	36	6	1	0	0	0	0	0	0	0	0	0	43
PER	5	275	45	7	0	0	0	0	0	0	0	0	0	327
FCY	6TO	19	4	0	0	0	0	0	0	0	0	0	0	23
PER	15	145	30	0	0	0	0	0	0	0	0	0	0	175
FCY	16TO	9	1	0	0	0	0	0	0	0	0	0	0	10
PER	25	68	7	0	0	0	0	0	0	0	0	0	0	75
FCY	26TO	11	6	0	0	0	0	0	0	0	0	0	0	17
PER	35	84	45	0	0	0	0	0	0	0	0	0	0	129
FCY	36TO	7	1	0	0	0	0	0	0	0	0	0	0	8
PER	45	53	7	0	0	0	0	0	0	0	0	0	0	60
FCY	46TO	3	2	0	0	0	0	0	0	0	0	0	0	5
PER	55	22	15	0	0	0	0	0	0	0	0	0	0	37
FCY	56TO	13	0	0	0	0	0	0	0	0	0	0	0	13
PER	65	99	0	0	0	0	0	0	0	0	0	0	0	99
FCY	66TO	10	2	1	0	0	0	0	0	0	0	0	0	13
PER	75	76	15	7	0	0	0	0	0	0	0	0	0	98
FCY	76TO	16	4	0	0	0	0	0	0	0	0	0	0	20
PER	85	122	30	0	0	0	0	0	0	0	0	0	0	152
FCY	86TO	11	0	0	0	0	0	0	0	0	0	0	0	11
PER	95	84	0	0	0	0	0	0	0	0	0	0	0	84
FCY	96TO	6	0	0	0	0	0	0	0	0	0	0	0	6
PER	105	45	0	0	0	0	0	0	0	0	0	0	0	45
FCY	106TO	2	0	0	0	0	0	0	0	0	0	0	0	2
PER	115	15	0	0	0	0	0	0	0	0	0	0	0	15
FCY	116TO	4	0	0	0	0	0	0	0	0	0	0	0	4
PER	125	30	0	0	0	0	0	0	0	0	0	0	0	30
FCY	126TO	13	0	0	0	0	0	0	0	0	0	0	0	13
PER	135	99	0	0	0	0	0	0	0	0	0	0	0	99
FCY	136TO	5	0	0	0	0	0	0	0	0	0	0	0	5
PER	145	38	0	0	0	0	0	0	0	0	0	0	0	38
FCY	146TO	6	2	0	0	0	0	0	0	0	0	0	0	8
PER	155	45	15	0	0	0	0	0	0	0	0	0	0	60
FCY	156TO	14	0	0	0	0	0	0	0	0	0	0	0	14
PER	165	107	0	0	0	0	0	0	0	0	0	0	0	107
FCY	166TO	11	0	0	0	0	0	0	0	0	0	0	0	11
PER	175	84	0	0	0	0	0	0	0	0	0	0	0	84
FCY	176TO	23	1	0	0	0	0	0	0	0	0	0	0	24
PER	185	175	7	0	0	0	0	0	0	0	0	0	0	182
FCY	186TO	35	16	0	0	0	0	0	0	0	0	0	0	51
PER	195	267	122	0	0	0	0	0	0	0	0	0	0	389
FCY	196TO	32	8	2	0	0	0	0	0	0	0	0	0	42
PER	205	244	61	15	0	0	0	0	0	0	0	0	0	320
FCY	206TO	27	10	5	0	0	0	0	0	0	0	0	0	42
PER	215	206	76	38	0	0	0	0	0	0	0	0	0	320
FCY	216TO	37	19	2	0	0	0	0	0	0	0	0	0	58
PER	225	283	145	15	0	0	0	0	0	0	0	0	0	443
FCY	226TO	35	25	1	0	0	0	0	0	0	0	0	0	61
PER	235	267	151	7	0	0	0	0	0	0	0	0	0	465
FCY	236TO	32	14	0	0	0	0	0	0	0	0	0	0	46
PER	245	244	107	0	0	0	0	0	0	0	0	0	0	351
FCY	246TO	27	9	0	0	0	0	0	0	0	0	0	0	36
PER	255	206	68	0	0	0	0	0	0	0	0	0	0	274
FCY	256TO	30	6	2	0	0	0	0	0	0	0	0	0	38
PER	265	229	45	15	0	0	0	0	0	0	0	0	0	289
FCY	266TO	28	3	0	0	0	0	0	0	0	0	0	0	31
PER	275	214	22	0	0	0	0	0	0	0	0	0	0	236
FCY	276TO	35	3	0	0	0	0	0	0	0	0	0	0	38
PER	285	267	22	0	0	0	0	0	0	0	0	0	0	289
FCY	286TO	34	1	0	0	0	0	0	0	0	0	0	0	35
PER	295	260	7	0	0	0	0	0	0	0	0	0	0	267
FCY	296TO	31	2	0	0	0	0	0	0	0	0	0	0	33
PER	305	237	15	0	0	0	0	0	0	0	0	0	0	252
FCY	306TO	39	21	0	0	0	0	0	0	0	0	0	0	60
PER	315	298	160	0	0	0	0	0	0	0	0	0	0	458
FCY	316TO	65	73	0	0	0	0	0	0	0	0	0	0	138
PER	325	497	558	0	0	0	0	0	0	0	0	0	0	1055
FCY	326TO	69	47	0	0	0	0	0	0	0	0	0	0	116
PER	335	527	359	0	0	0	0	0	0	0	0	0	0	886
FCY	336TO	44	14	0	0	0	0	0	0	0	0	0	0	58
PER	345	336	107	0	0	0	0	0	0	0	0	0	0	443
FCY	346TO	32	9	0	0	0	0	0	0	0	0	0	0	41
PER	355	244	68	0	0	0	0	0	0	0	0	0	0	312
	SUM	851	309	14	0	0	0	0	0	0	0	0	0	
		6452	2349	104	0	0	0	0	0	0	0	0	0	

Total No. Observations = 1307
Frequency Calm = 133 Per cent Calm = 10.17
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

Wind Distribution -- Speed vs Direction
During Periods of Temperature Inversion
December 1964-1966: 100 Ft. Level

Wind Speed Interval (Kts)

Wind Direction Interval (Degrees)

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     DIR      1-    6-   11-   16-   21-   26-   31-   36-   41-   46-   51-  OVER   SUM
     DEG       5    10    15    20    25    30    35    40    45    50    55    55
FCY 356TO     19     0     0     0     0     0     0     0     0     0     0     0    19
PER 5        174     0     0     0     0     0     0     0     0     0     0     0   174
FCY 6TO       17     6     0     0     0     0     0     0     0     0     0     0    23
PER 15       156    55     0     0     0     0     0     0     0     0     0     0   211
FCY 16TO       7     1     0     0     0     0     0     0     0     0     0     0     8
PER 25        64     9     0     0     0     0     0     0     0     0     0     0    73
FCY 26TO       5     0     0     0     0     0     0     0     0     0     0     0     5
PER 35        45     0     0     0     0     0     0     0     0     0     0     0    45
FCY 36TO       6     0     0     0     0     0     0     0     0     0     0     0     6
PER 45        55     0     0     0     0     0     0     0     0     0     0     0    55
FCY 46TO       3     0     0     0     0     0     0     0     0     0     0     0     3
PER 55        27     0     0     0     0     0     0     0     0     0     0     0    27
FCY 56TO       2     1     0     0     0     0     0     0     0     0     0     0     3
PER 65        18     9     0     0     0     0     0     0     0     0     0     0    27
FCY 66TO       2     0     0     0     0     0     0     0     0     0     0     0     2
PER 75        18     0     0     0     0     0     0     0     0     0     0     0    18
FCY 76TO       7     1     0     0     0     0     0     0     0     0     0     0     8
PER 85        64     9     0     0     0     0     0     0     0     0     0     0    73
FCY 86TO       6     0     0     0     0     0     0     0     0     0     0     0     6
PER 95        55     0     0     0     0     0     0     0     0     0     0     0    55
FCY 96TO       6     0     0     0     0     0     0     0     0     0     0     0     6
PER 105       55     0     0     0     0     0     0     0     0     0     0     0    55
FCY 106TO      6     0     0     0     0     0     0     0     0     0     0     0     6
PER 115       55     0     0     0     0     0     0     0     0     0     0     0    55
FCY 116TO      8     0     0     0     0     0     0     0     0     0     0     0     8
PER 125       73     0     0     0     0     0     0     0     0     0     0     0    73
FCY 126TO     12     0     0     0     0     0     0     0     0     0     0     0    12
PER 135      110     0     0     0     0     0     0     0     0     0     0     0   110
FCY 136TO      6     1     0     0     0     0     0     0     0     0     0     0     7
PER 145       55     9     0     0     0     0     0     0     0     0     0     0    64
FCY 146TO      4     2     0     0     0     0     0     0     0     0     0     0     6
PER 155       36    18     0     0     0     0     0     0     0     0     0     0    54
FCY 156TO     13     2     0     0     0     0     0     0     0     0     0     0    15
PER 165      119    18     0     0     0     0     0     0     0     0     0     0   137
FCY 166TO     14     3     0     0     0     0     0     0     0     0     0     0    17
PER 175      128    27     0     0     0     0     0     0     0     0     0     0   155
FCY 176TO     22    12     1     0     0     0     0     0     0     0     0     0    35
PER 185      202   110     9     0     0     0     0     0     0     0     0     0   321
FCY 186TO     50    19     0     0     0     0     0     0     0     0     0     0    69
PER 195      459   174     0     0     0     0     0     0     0     0     0     0   633
FCY 196TO     43    28     1     0     0     0     0     0     0     0     0     0    72
PER 205      395   257     9     0     0     0     0     0     0     0     0     0   661
FCY 206TO     50    34     5     0     0     0     0     0     0     0     0     0    89
PER 215      459   312    45     0     0     0     0     0     0     0     0     0   816
FCY 216TO     22    16     0     0     0     0     0     0     0     0     0     0    38
PER 225      202   147     0     0     0     0     0     0     0     0     0     0   349
FCY 226TO     24     0     0     0     0     0     0     0     0     0     0     0    24
PER 235      220     0     0     0     0     0     0     0     0     0     0     0   220
FCY 236TO     29     6     0     0     0     0     0     0     0     0     0     0    35
PER 245      266    55     0     0     0     0     0     0     0     0     0     0   321
FCY 246TO     21     1     2     0     0     0     0     0     0     0     0     0    24
PER 255      193     9    18     0     0     0     0     0     0     0     0     0   220
FCY 256TO     24     5     0     0     0     0     0     0     0     0     0     0    29
PER 265      220    45     0     0     0     0     0     0     0     0     0     0   265
FCY 266TO     44     1     0     0     0     0     0     0     0     0     0     0    45
PER 275      404     9     0     0     0     0     0     0     0     0     0     0   413
FCY 276TO     39     1     0     0     0     0     0     0     0     0     0     0    40
PER 285      358     9     0     0     0     0     0     0     0     0     0     0   367
FCY 286TO     45     0     0     0     0     0     0     0     0     0     0     0    45
PER 295      413     0     0     0     0     0     0     0     0     0     0     0   413
FCY 296TO     40     0     0     0     0     0     0     0     0     0     0     0    40
PER 305      367     0     0     0     0     0     0     0     0     0     0     0   367
FCY 306TO     36     6     1     0     0     0     0     0     0     0     0     0    43
PER 315      331    55     9     0     0     0     0     0     0     0     0     0   395
FCY 316TO     43    14     0     0     0     0     0     0     0     0     0     0    57
PER 325      395   128     0     0     0     0     0     0     0     0     0     0   523
FCY 326TO     51     9     0     0     0     0     0     0     0     0     0     0    60
PER 335      469    82     0     0     0     0     0     0     0     0     0     0   551
FCY 336TO     15     6     0     0     0     0     0     0     0     0     0     0    21
PER 345      137    55     0     0     0     0     0     0     0     0     0     0   192
FCY 346TO     15     2     0     0     0     0     0     0     0     0     0     0    17
PER 355      137    18     0     0     0     0     0     0     0     0     0     0   155

    SUM      756   177    10     0     0     0     0     0     0     0     0     0
            6934  1619    90     0     0     0     0     0     0     0     0     0
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Total No. Observations = 1087
Frequency Calm = 144 Per cent Calm = 13.24
FCY = frequency of occurrence
PER = per cent of occurrence of total observations
Two observations/hour: Temp. gradient ≥ 2F°/570 Ft.

APPENDIX E

EVALUATION OF SUTTON'S EQUATIONS FOR DIFFERENT ENVIRONMENTAL SITUATIONS[1]

The use of the Sutton equations at a particular site requires the adjustment of certain of his coefficients. Sutton assumed a smooth lower boundary. When the surface of the earth in the vicinity of the particular site is not smooth and level, values of C_z in his equations must be modified accordingly. Data to provide information on the exact amount of the change in C_z with changing surface configuration are lacking, but it might be reasonable to assume that the change is in some manner proportional to the variation in grade of the surface.

Sutton also assumed that turbulence was isotropic above the 80-foot level. Everyday observations of high level smoke emissions indicate the non-validity of this assumption. At the same time there is no basis for such an assumption when ground-level concentrations of pollutants are to be calculated, for particles of pollution must diffuse through the lower air layers where turbulence is nonisotropic in reaching the ground. Thus, the ratio of C_z/C_y is probably not unity even with high stacks if ground-level concentrations are being calculated.

Based on these considerations, Davis (1957) has provided a series of values for the Sutton coefficients for a rolling or hilly topography. His values are included in table 1 for information along with Sutton's suggested values. It must be remembered that these are order of magnitude values and little experimental proof of their validity is available.

Sutton (1947) states that when the stability condition of the atmosphere is neutral, n, in his equation equals 0.25. In very turbulent air, n approaches zero. Under very stable conditions, n approaches unity. The use of Sutton's equations with values of n greater than 0.50 is not recommended. Under strongly stable conditions, contaminants emitted from a stack may remain at the original level as they drift in a very slowly widening horizontal band. When this condition occurs, the equations may overestimate ground concentrations. During the brief period of inversion breakup, when the atmosphere is changing from a stable to an unstable condition, ground concentrations may be well above the maximum specified by Sutton's equations. Based on data from the Brookhaven National Laboratory, use of the Sutton equations with some of the coefficient values suggested by Sutton provides concentrations of the order of limiting maximum values rather than time-average values as specified in the derivation of the equations.

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[1] This appendix has been adopted from pp. 83-86 in Thornthwaite, Mather and Davis, 1960.

Table 1

a) Diffusion Coefficients with Height and Lapse Rate According to Sutton

Height of Source Above Ground, Feet	Large Lapse Rate n = 0.20		Small Lapse Rate n = 0.25		Moderate Inversion n = 0.33		Large Inversion n = 0.50	
	C_y	C_z	C_y	C_z	C_y	C_z	C_y	C_z
0	0.42	0.24	0.24	0.14	0.15	0.09	0.12	0.07
30	0.42	0.24	0.24	0.14	0.15	0.09	0.12	0.07
80	0.24		0.14		0.090		0.070	
100	0.23		0.13		0.085		0.065	
150	0.21		0.12		0.075		0.060	
200	0.19		0.11		0.070		0.055	

b) Suggested Diffusion Coefficients with Height and Lapse Rate for Rolling or Hilly Terrain (local topography has approximately a 20% grade) (After Davis, 1957)

Height of Source Above Ground, Feet	Large Lapse Rate n = 0.20		Small Lapse Rate n = 0.25		Moderate Inversion n = 0.33		Large Inversion n = 0.50	
	C_y	C_z	C_y	C_z	C_y	C_z	C_y	C_z
80	0.42	0.29	0.36	0.17	0.30	0.12	0.24	0.09
100	0.40	0.27	0.34	0.16	0.28	0.12	0.23	0.09
150	0.38	0.26	0.32	0.15	0.27	0.11	0.22	0.08
200	0.36	0.25	0.31	0.15	0.26	0.11	0.21	0.08

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